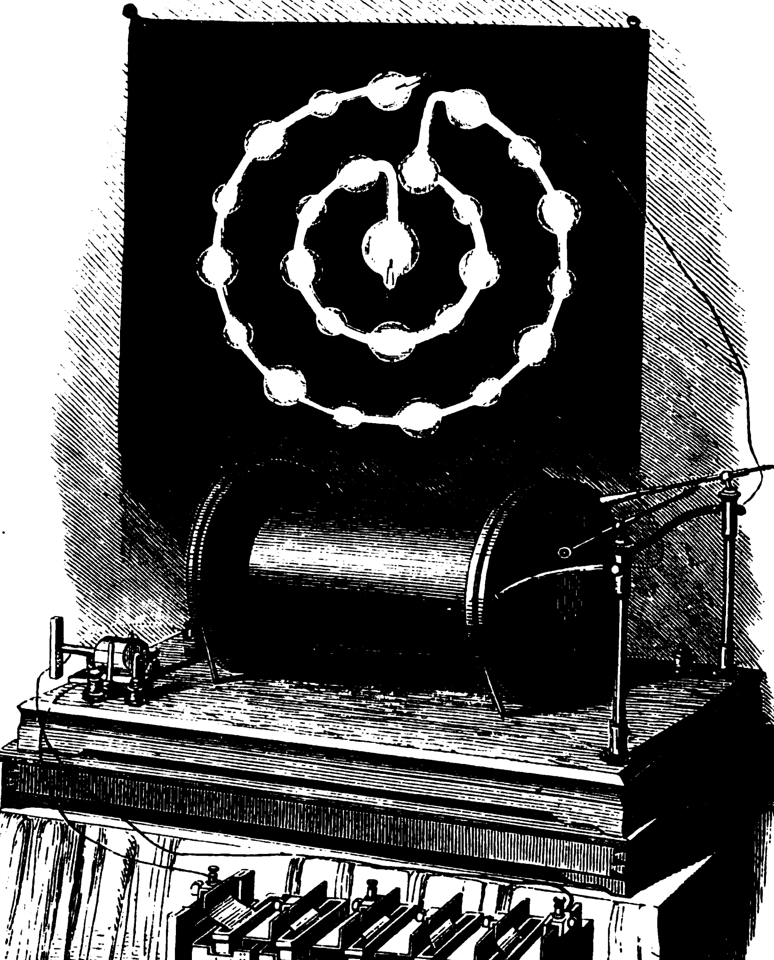
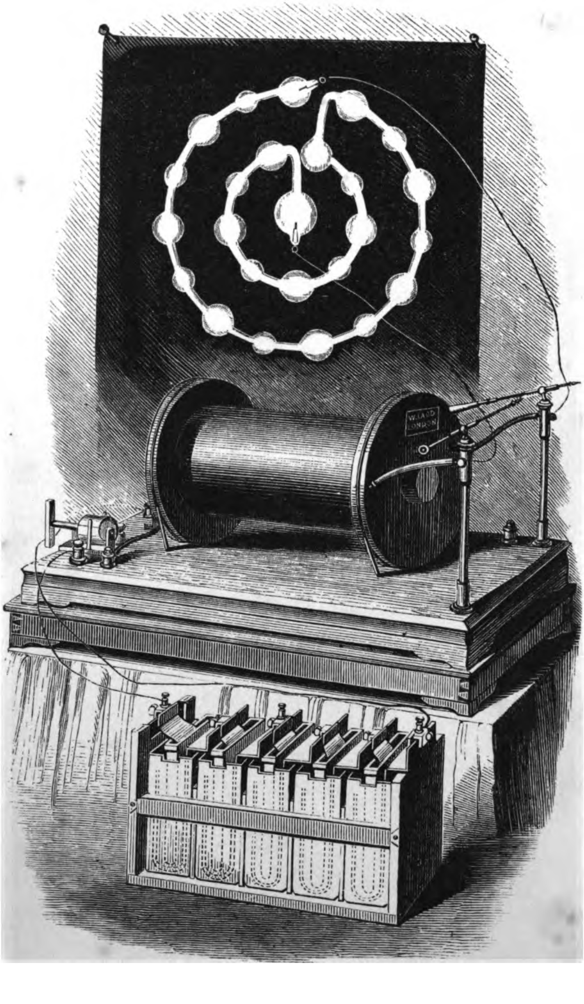


The improved induction coil

Henry Minchin Noad

Frontispiece.



THE

Improved Induction Coil;

BEING

A POPULAR EXPLANATION

OF THE

ELECTRICAL PRINCIPLES

ON WHICH IT IS CONSTRUCTED.

WITH

THE DESCRIPTION OF A SERIES OF BEAUTIFUL AND INSTRUCTIVE EXPERIMENTS,

ILLUSTRATIVE OF

The Phenomena of the Induced Current.

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1861.

THE

IMPROVED INDUCTION COIL.

1.—Discovery of Electro-Magnetism.

In the year 1820, Professor Oersted, of Copenhagen, announced his famous discovery of the reciprocal force exerted between magnetic bars and wires uniting the opposite terminals of a voltaic battery, and thus laid the foundation of a new science — that of Electro-Magnetism. The discovery of the Danish philosopher was thus simply stated:—When a properly-balanced magnetic needle is placed in its natural position in the magnetic meridian, immediately under, and parallel to, a wire along which a current of voltaic electricity is passing, that end of the needle which is situated next to the negative side of the battery immediately moves to the *west;* if the needle is placed parallel to and over the wire, the same pole moves to the *east*. When the uniting wire is situated in the same horizontal plane as that in which the needle moves, no declination takes place, but the needle is inclined, so that the pole next to the negative end of the wire is depressed when the wire is situated on the west side, and elevated when situated on the east side. To assist the memory in retaining the directions of these deviations, Ampere devised the following formula:—"Let any one identify himself with the current, or let him suppose himself

lying in the direction of the positive current, his head representing the copper and his feet the zinc plate, and looking at the needle; its *north* pole will always move towards his right hand."

2.—Electro-Magnetic Rotation.

Reasoning on the fact that this action of a conducting wire on a magnet is not a directly attractive or a repulsive one, Faraday was led to the conclusion that if the action of the voltaic current could be confined to one pole of the magnet, that pole ought, under proper conditions, to rotate round the wire; and conversely, if the magnet were fixed and the conducting wire moveable, the wire ought to rotate round the magnetic pole; both of these phenomena he realised, and described the apparatus for exhibiting them in the "Quarterly Journal of Science," Vol. XII., p. 283 (January, 1822). Ampere subsequently caused a magnet to rotate round its own axis; and Barlow devised an ingenious apparatus for exhibiting the rotation of a conducting body round its axis.

3.—The Galvanometer.

Shortly after the discovery of Oersted, Schweigger, a German physicist, applied it to the construction of an apparatus for indicating the direction and measuring the intensity of voltaic currents. This instrument is called the multiplier or rheometer, or more popularly the galvanometer. In its original form it consisted of a rectangular coil of silk or cotton-covered copper wire, in the centre of which was suspended, on a pivot, a magnetic needle, and a card graduated into 360 degs.; the instrument being so placed that the needle lies parallel to the coil; on causing a current of electricity to circulate through the latter, the needle becomes

violently affected, even by very feeble currents, it being obvious, from a consideration of Oersted's fundamental law, that the needle, being placed between the two horizontal branches of the conducting wire, will be impelled in the same direction by the current traversing the wire above and below it. A great improvement was subsequently made in the instrument by Cumming and Nobili, who applied the astatic needle to the multiplier, thereby greatly increasing its sensibility, by annulling the directive action of the earth on the needle. There appears to be scarcely any limit to the sensibility which the galvanometer may be made to attain; as far as experiment has yet gone, it increases in delicacy in proportion to the length, purity, and insulation of the copper wire composing the coil. Du Bois-Reymond constructed, for his researches on the currents of electricity existing in animal structures, a multiplier, the length of which was 16,752 feet long, and passed round the frame 24,160 times; the sensibility of this instrument is almost incredible. The galvanometer is an indispensable instrument to those engaged in electrical researches.

4.—Electro-dynamics.

When two wires are traversed simultaneously by an electrical current, attractions or repulsions ensue, similar to those which take place between the poles of two magnets. If the currents are moving in the same direction in the two wires, they mutually attract; if in a contrary direction, they mutually repel. This discovery we owe to Ampere, and the discussion of the phenomena to which it gave rise constitutes the science of electro-dynamics. The analogy between wires conducting electricity and magnets is strikingly illustrated by turning the wires corkscrew fashion, making them helices. A helix has, indeed, all the properties of a

magnet, but the nature of the pole at either end will depend on the direction of the turns of the helix; if these be from left to right, then the extremity at which the current enters will have the magnetic properties of a north pole; but if the helix be a left-handed one, then the extremity at which the current enters will have the properties of a south pole, and that at which it goes out those of a north pole. The analogy extends to fracture. If a magnetic bar be broken in two, each piece is a perfect magnet, and the fractured parts have opposite poles; so it is with a helix, which, if divided in the middle, exhibits attraction between the fractured ends. If a helix be suspended vertically and loosely, its upper end being held by a binding screw, and its lower end dipping into mercury; and if a voltaic current be passed along it whilst thus suspended, there will be mutual attraction manifested between the coils, and the helix will be contracted.

5.—Ampere's Theory of Magnetism.

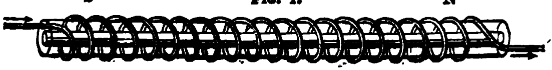
On the analogy which exists between helices and magnets Ampere founded his theory of magnetism. According to this theory, the phenomena of magnetism depend on voltaic currents circulating round the molecules of the magnetic bodies. In their unexcited state these molecular currents move in all directions, and thus neutralise one another; but when the bar becomes a magnet, the currents move parallel to each other, and in the same direction, and the effect produced is that of a uniform current moving corkscrew fashion round the bar, which thus becomes in effect a helix, and the attractions and repulsions of the magnet are consequences of the actions of the currents on each other. In applying this theory to the explanation of the phenomena of terrestrial magnetism, it is necessary to suppose the incessant circulation of electrical currents round the globe

from east to west perpendicular to the magnetic meridian.

6.—Magnetism excited by Electricity.

A consideration of the influence exerted by electrical currents on magnets, leads naturally to the conclusion that the neutral condition of bodies susceptible of magnetism would be disturbed by an electrical current, and that they would become magnetic, and the fact is easily verified by plunging the wire uniting the opposite poles of a voltaic battery into iron filings, which attach themselves to the wire, and remain adhering to it as long as the current continues to circulate, but drop off the moment the circuit is interrupted; filings of copper or tin exhibit no such action. The magnetising power of electricity is also illustrated by winding a silk or cotton-covered copper wire round a glass tube enclosing an unmagnetised steel needle and connecting the ends of the helix with the terminal plates of the voltaic battery; the needle becomes magnetised to saturation even by a momentary passage of the current through the helix; the magnetisation of the needle also takes place if, instead of passing the current from a voltaic battery along the helix, a Leyden phial be discharged through it, an interesting experiment, as proving the magnetising power of ordinary (statical) as well as of voltaic (dynamical) electricity. The sense in which the needle will be magnetised will depend on the nature of the helix; if it be a right-handed one, as—

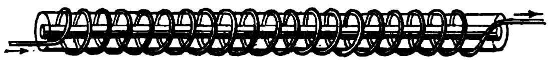
Fig. 1.



the north pole of the needle will be formed towards

the extremity at which the current enters; if the helix be left-handed, as—

N FIG. 2. S



then the end of the needle nearest the extremity at which the current enters will be a south pole. A tube of wood may be substituted for one of glass in this experiment, but not one of copper, which, if thick, destroys entirely the effect of the current. The tube in this experiment may be altogether dispensed with, and the silk or cotton-covered copper wire wound round the steel bar itself, which thus becomes intensely and permanently magnetised by a very feeble current. Soft iron, treated in a similar manner, acquires a high degree of temporary magnetism—iron, if pure, not being able to retain the magnetic force, although if not pure, it does not wholly lose its polarity. Bars of iron thus temporarily magnetised by the voltaic current are called electro-magnets; they are generally made horse-shoe shape, the covered copper wire being wound several times round each arm in the same direction; the ends of the curved bar acquire opposite magnetic polarity, the north pole being formed at the extremity at which the current enters. The power of the electro-magnet depends on the dimensions and purity of the iron, the intensity of the current, and on the length and thickness of the wire. It has been shown by Dub, that the power of the electro-magnet to affect a magnetic needle and to sustain weights, is proportional to the square root of the diameter of the bar. The applications of the electro-magnet to electro-telegraphy, to the construction of electro-magnetic and horological machines, and to the elucidation of the phenomena of

diamagnetism, have received important developments during the last few years.

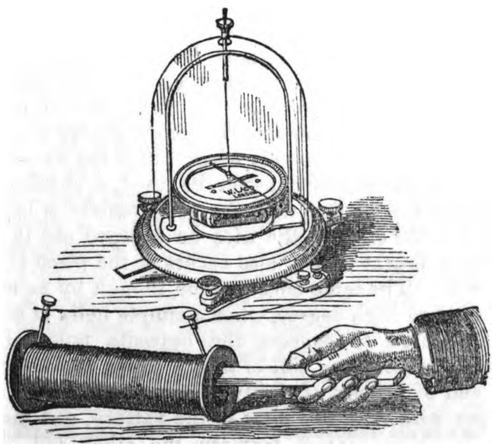
7.—Induction of Electrical currents.

On the 21st of November, 1831, the first series of Faraday's celebrated "Experimental Researches in Electricity" was read before the Royal Society. It related to the induction of electric currents. Two hundred and three feet of copper wire in one length were coiled round a large block of wood; other two hundred and three feet of similar wire were interposed as a spiral between the turns of the first coil, and metallic contact everywhere prevented by twine. One of these helices was connected with a galvanometer, and the other with a powerful voltaic battery. When contact was made, there was a sudden effect at the galvanometer, and a similar slight effect when the contact with the battery was broken; but whilst the voltaic current was continuing to pass through the one helix, no galvanometrical appearances, nor anything like induction upon the other helix could be perceived. The force of the induced current, which partook of the nature of an electrical wave, passed through from the shock of a common Leyden jar, was greater on making than on breaking contact; the direction of the current was, on making contact, the reverse of that of the inducing current, but on breaking contact it was in the same direction as that of the battery current. When the helices of copper wire were wound round a ring of soft iron, but carefully insulated from it, the effects were far greater, but they were not more permanent, the galvanometer needle speedily reassuming its natural position while battery contact was maintained, but being again powerfully deflected in the contrary direction the instant the contact was broken. When the ends of the helices were tipped with charcoal, a spark could be obtained at the moment

of making contact between the other helix and the poles of the battery. Faraday next wound a similar series of helices round a hollow cylinder of pasteboard, and connected the respective ends with the galvanometer. He then introduced into the axis of the cylinder a soft iron bar, which he made temporarily magnetic, by bringing its opposite ends into contact with the opposite poles of two powerful bar magnets; the moment this was done, the needle was deflected; continuing the contact, the needle became indifferent, and resumed its first position. On breaking contact it was again deflected, but in the opposite direction, and then it again became indifferent. When the magnetic contacts were reversed, the deflections were reversed likewise. Here, then, was a distinct evolution of electricity from magnetism alone. The action of the current from the voltaic battery is called *volta-electric induction;* that produced by the magnet is called *magneto-electric induction*, and the reason why the effects at the galvanometer are so much greater when the helices are arranged round an iron bar, than when they are coiled simply round a block of wood, is because, in the former case, we have volta-electric and magneto-electric induction combined, whereas, in the latter case, the effect is due to the action of volta-electric induction only. Powerful effects at the galvanometer were obtained on bringing the ends of the system of helices with an enclosed iron cylinder, between the poles of a strong magnet, and even when the coil, without the iron core, was introduced between the poles of the magnet, but without touching, so that the only metal near the magnet was copper, the needle of the galvanometer was thrown 80°, 90°, or more, from its natural position. Faraday was unable to obtain chemical effects by the induced current, but on repeating his experiments with an armed loadstone capable of lifting about thirty pounds, he succeeded in convulsing powerfully the limbs of a frog, and in obtaining physiological

effects upon himself. An important element in magneto-electric induction, which was noticed by Faraday during the prosecution of his earliest experiments, is *time*. Volta-electric induction is sudden and instantaneous, but magneto-induction requires sensible time, and experiment proves that an electro-magnet does not rise to its fullest intensity in an instant. Fig. 3 shows a convenient arrangement for exhibiting and

FIG. 3.



illustrating magneto-electric induction. Two or three hundred feet of cotton or silk-covered copper wire are wound round a hollow pasteboard or wooden cylinder, and the ends connected with a galvanometer placed at a distance. On thrusting a tolerably powerful bar magnet into the axis of the cylinder, the needle is immediately and strongly deflected; on allowing the bar to remain at rest, it soon regains its natural posi-

tion, but is again deflected in an opposite direction when the magnet is suddenly withdrawn; the motions of the needle are reversed when the opposite end of the magnet is thrust into the cylinder.

8.—Induction of a current on itself.

In his ninth series of Experimental Researches, read before the Royal Society, Jan. 29th, 1835, Faraday makes known a new action of the electric current, viz., an induction on itself. The inquiry arose out of a fact communicated by Mr. Jenkin, which is as follows:—If an ordinary wire of short length be used as the medium of communication between the two plates of an electrometer, consisting of a single pair of metals, no management will enable the experimenter to obtain an electric shock from this wire; but if the wire which surrounds an electro-magnet be used, a shock is felt each time the contact with the electrometer is broken, provided the ends of the wire be grasped one in each hand; a bright spark also occurs at the place of disjunction. The same effects occur, though by no means in the same high degree, when a simple helix of copper wire is used to connect the opposite poles of the battery without any coil of iron. Thus on connecting one end of a helix of eighty or a hundred feet of stout copper wire with one plate of the battery, and making and breaking contact between the other end of the helix and the opposite pole of the battery, which is best done by dipping it into, and quickly withdrawing it from, a cup of mercury in good metallic connection with the battery, a distinct shock is experienced every time the wire leaves the mercury, although none can be perceived when it enters the fluid metal. If the same quantity of wire be used, not in the form of a helix, the spark is much less bright on breaking contact, nor can any, or only very feeble, physiological

effects be obtained; the phenomenon is best observed by taking about 100 feet of copper wire and winding 50 feet into a helix, then bending it in the middle so as to form a double termination, and allowing the other 50 feet to remain extended; on using each half of the wire alternately as the connecting wire of an electrometer, the helix will be found to give by far the brightest spark; it even gives a brighter spark than when it is used in conjunction with one extended half of the wire. The brightness of the spark with the helix is however no proof that more electricity, or electricity of higher intensity, is passing through it than through the extended wire connecting the plates of the battery. Faraday found the effect at the galvanometer and the electrolyzing power to be the same, whether he used a short wire, a long wire, a helix, or an electro-magnet; under certain circumstances, however, proof can be obtained that there is a diminution of the battery current when a long wire is used, in consequence of the resistance it sets up; thus, on soldering an inch or two of fine platinum wire to one end of a long wire, and also a similar length to one end of a short wire, and then using each to connect the plates of the same electrometer, Faraday found that the latter became ignited, though producing but a feeble spark, while the former remained cold, though giving a bright spark. This bright spark is due to a momentary extra current induced in the wire at the moment the primary or inducing current from the battery ceases to flow through the wire. This extra current, or wave of electricity, may be examined as to direction and intensity by a very simple expedient; thus, by using an electro-magnet, and connecting the ends of the principal wire by a short cross-wire, the bright spark ceases to appear in the mercury cup on breaking battery contact, because the extra current which would have produced it now passes along the connecting wire. If

the cross-wire be divided in the middle, a spark may be obtained by rubbing the two ends together, while contact is broken and renewed between one of the principal terminal wires, and one of the mercury cups of the battery; chemical decomposition may also be effected there, and a fine platinum wire ignited. The direction of the extra-current is shown by introducing a galvanometer between the divided ends of the cross wire; whilst the current from the battery is circulating the helix of the electro-magnet, the galvanometer is affected in the direction of the battery current, because the cross-wire carries one part of the electricity excited by the battery; but, if the needle be forced back to its normal position, and secured there by pins, and if battery contact be then broken, the needle is powerfully deflected in an opposite direction, thus proving that the wave of induced electricity—the extra current—moves in the wire, at the moment of disruption with the battery, in a direction contrary to that of the electrical current set in motion by the battery itself.

9.—Extra-current.

This extra current may be removed from the wire carrying the original current to a neighbouring wire; if two helices be arranged on the same hollow pasteboard or wooden cylinder, in close proximity, but nowhere actually touching, and one used for making and breaking contact with a battery, the usual bright spark appears at the moment of disruption; but if the two ends of the second helix be brought into contact, so as to form an endless wire, the spark becomes scarcely sensible, and all the phenomena described (8) as occurring between the divided ends of the cross wire may be re-produced between the two extremities of the second helix. "The case," therefore, says

Faraday, "of the bright spark shock on disjunction may now be stated thus:—If a current be established in a wire, and another wire, forming a complete circuit, be placed parallel to the first, at the moment the current in the first is stopped it induces a current in the same direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire induces a current in itself in the same direction, producing a strong spark. The strong spark in the single long wire or helix, at the moment of disjunction, is therefore the equivalent of the current which would be produced in a neighbouring wire if such a second current were permitted." A brighter spark, then, is produced at the moment of disruption of a long wire joining the plates of a battery than of a short wire, because, though it carries less electricity, it induces on itself a more powerful wave current; if wound into a coil, the spark is still brighter, because of the mutual inductive action of the convolutions, each aiding its neighbour; and the brightness of the spark is exalted still higher when the coil encloses a bar of soft iron, because the bar, losing its magnetism at the moment of disruption, tends to produce an electric current in the wire around it, in conformity with that which the cessation of the current in the helix itself also tends to produce. It is not so easy to demonstrate the induction of a wave current at the moment of making contact; but by using certain expedients, Faraday succeeded in doing so; thus, when a galvanometer was introduced between the ends of the cross-wire, a part of the current from the battery was diverted through it; when the needle had taken up its position it was retained there by pins, contact was then broken, but the needle was prevented from obeying the impulse which the reverse wave would have given to it by the stops; contact being now again made, the needle immediately moved onwards, showing, by a

temporary excess of current in the cross communication, a temporary retardation in the helix.

10.—Induction of Secondary currents at a distance.

On the 2nd of November, 1838, a memoir on electro-magnetic induction was read at the meeting of the American Philosophical Society, by Dr. Joseph Henry, professor of natural philosophy in the College of New Jersey, Princeton. This ingenious electrician employed in his experiments flat coils of insulated copper riband, and helices and spocls of fine covered copper wire; with electricity of low intensity, as from a single pair of plates, he obtained with a flat riband coil 93 feet long brilliant deflagrations and loud snaps from a surface of mercury, but no shocks; but when the length of the riband was increased to 300 feet he obtained strong shocks but less brilliant sparks; with electricity of higher intensity as from a series of pairs of plates, the action of the riband was decreased, but when the current from ten pairs was sent through a spool of wire one-sixteenth of an inch in diameter and five miles long, the induced shock was too severe to be taken through the body, though the spark was feeble; a shock was indeed passed through twenty-six persons at once from this spool, when a battery consisting of six pieces of copper bell wire and corresponding pieces of zinc wire, only one-and-a-half inch long, was employed; nevertheless when a single pair of plates exposing one square foot and three-quarters of zinc surface was used, scarcely any physiological effects could be obtained. In these experiments contact with the battery was broken and renewed by drawing one end of the riband or helix across a rasp which was kept in good metallic contact with one of the plates of the battery. When the current from a small battery

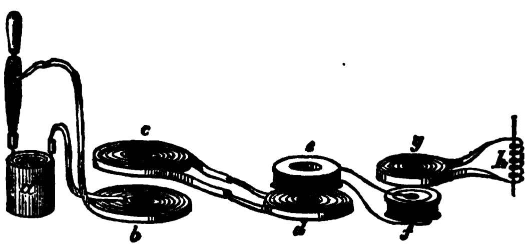
was sent through a copper riband on the top of which was placed a helix containing 3,000 yards of covered copper wire 0·02 inch in diameter, a plate of glass being interposed between the riband and the helix; powerful shocks were obtained from the latter as often as the current through the former was interrupted; when the helix was removed and a copper riband sixty feet long substituted for it, very feeble shocks could be obtained; but sparks were produced; on rubbing the ends of the riband together, needles were magnetised, temporary magnetism in soft iron was developed, and water was decomposed; none of these latter effects could, however, be obtained with the helix. Intense shocks, and magnetising, and chemical effects also were obtained from the five-miles spool of wire when the riband was opened so as to receive it in the centre, and an interrupted current from a single pair of plates sent through the riband. From these experiments it will be seen that the induced or secondary current obtained from ribands or short stout copper wire partakes of the character of what is called *quantity*, while that from great lengths of fine wire exhibits the qualities of what is termed *intensity*. When the current from an extensive series of plates was sent through a riband and intermitted, no secondary effects could be obtained in the helix, but when the same battery was used with a helix, powerful shocks were induced in a second helix, and sparks and magnetising effects obtained with a riband; "hence," observes Henry, "an intensity current can induce one of quantity, and a quantity current can induce one of intensity." The induction of a secondary current at a distance from the primary was illustrated by Dr. Henry in a surprising manner, by coiling the wire of the five-mile spool into a ring four feet in diameter, and placing parallel to it another ring of copper riband 270 feet long; on sending an intermitting current from

a single pair of plates, zinc surface 35 feet, through the latter, shocks could be obtained from the former at a distance of four feet, and at a distance of twelve inches they were too severe to be taken through the body.

11.—Induced Currents of the Third, Fourth, and Fifth Order.

Professor Henry was the first to show that the induction of electricity does not stop with the production of secondary currents, but that currents of a third, fourth, and even of a fifth order may be obtained. An intermittent current from a single pair of plates was sent through a copper riband, a second riband being placed over it to receive the induced secondary current. The ends of this second riband were connected with the ends of a third placed at a distance, and over this a helix of 1,660 feet of fine wire. On grasping copper handles metallically connected with the ends of this helix, powerful shocks were obtained; thus the secondary current produced a new induced current in a third conductor. By a similar arrangement shocks were received from currents of a fourth and fifth order, and with a more powerful primary current and additional coils, a still greater number of successive inductions might be obtained. The arrangement of coils and helices is shown in Fig. 4, where *a* represents a cylindrical copper

FIG. 4.



and zinc single-cell battery; *b*, a coil of copper riband, about 100 feet long, and an inch and a half wide; *c* and *d* similar ribands, about 60 feet long; *e*, a helix of 1,660 yards of copper wire, one forty-ninth of an inch in diameter; *f*, a helix of about 1,200 yards of the same wire; *g*, a copper riband, 60 feet long, and three-quarters of an inch wide; and *h*, a cylinder of about thirty spires of copper wire, so small as just to admit a sewing needle into its axis. Now here, as with a primary current only, it is found that a quantity current can be induced from one of intensity, and the converse; for the induction from coil, *b*, to helix, *e*, produces an intensity current, and from helix, *f*, to coil, *g*, a quantity one, as is demonstrated by the magnetisation of the steel needle in the copper spiral *h*. Then, as to the direction of these induced currents, it was found that there exists an alteration in the direction of the several orders, commencing with the secondary, as follows:—

Primary current	+
Secondary current	+
Current of the third order ...	—
Current of the fourth order ...	+
Current of the fifth order ...	—

the directions being determined by the nature of the polarity of the magnetised needle, by decomposition, and by the galvanometer. Induced currents of the different orders are also produced from ordinary electricity. On discharging a large Leyden phial through a spiral of tinfoil pasted round a glass cylinder, a similar spiral of foil being pasted inside the cylinder, the ends of which were connected with a magnetising spiral enclosing a steel needle, the latter was magnetised in such a manner as to indicate an induced current through the inner riband in the same direction as that of the current of the jar; a spark was also produced, when the ends of the spiral were separated

by a small interval. Induced currents of a third and fourth order were obtained when a large Leyden phial was substituted for the battery, the coils being furnished with a double coating of silk, and the conductors separated by a plate of glass. By using a powerful Leyden battery, Dr. Henry obtained evidence of the induction of a secondary current at the surprising distance of twelve feet. This subject has more recently been investigated by Reiss, who found that the currents of the third, fifth, and other *odd* orders have the same direction as the original current, and those of the second, fourth, and other *even* orders, have among themselves one and the same direction.

12.—The Electro-magnetic Coil Machine.

We are now prepared to understand the *modus operandi* of those elegant arrangements, which in so many forms have been rendered familiar to the scientific world for the last twenty years under the general name of the Electro-magnetic Coil. The first instrument which obtained public notoriety was designed by Professor Callan, of Maynooth College. It consisted of a coil of thick, insulated, copper bell-wire, wound on a small bobbin, to serve as the primary coil, and of a coil of about 1,500 feet of thin insulated wire wound round a larger cylinder, into the axis of which the smaller coil could be introduced to act as the secondary. The ends of each coil are attached to binding screws, to establish, on the one hand, a communication between the primary coil and the battery, and on the other, for the convenience of interposing any apparatus on which the effects of the secondary current are to be tested. Various contrivances have been adopted for breaking and renewing battery contact, some of an automatic character, others requiring manual assistance. Dr. Bird was the first in this country, at least, to employ the

permanent magnet to effect rupture of contact; this he did by causing a small bar electro-magnet to vibrate between the opposite poles of a pair of steel horseshoe-magnets in such a manner that every time each arm of the electro-magnetic bar rose and fell it should effect a disruption and a renewal of contact between the battery and the primary coil; in this way he obtained 300 oscillations in a minute, and a series of induced currents, capable not only of communicating a series of intense shocks, but of exerting powerful electrolytic action; when a bundle of soft iron wires was introduced into the axis of the primary, both shocks and chemical action were greatly exalted, and the sparks at the contact-breaker much increased in brilliancy, and were accompanied by a loud snapping noise and a vivid combustion of the mercury. In other arrangements the coil is placed vertically, and battery contact broken and renewed by the rotation of a soft iron bar, mounted between two brass pillars, and situated immediately over the axis of the coil, in which is placed a bundle of iron wires; in others a small disc of iron is kept vibrating, with amazing rapidity, over the bundle of iron wires, contact being broken and renewed between surfaces of platinum, which dispenses with the use of mercury. Mr. Henley, some years ago, made and presented to the writer a very powerful electro-magnetic machine, consisting of a series of U-shaped bars of soft iron, round which were wound four coils of No. 34 wire. Contact was broken and renewed by mercury. With this instrument a secondary spark could be obtained passing one-eighth of an inch through air; by a very simple contrivance the ends of the secondary coil could be united and disunited by merely turning an ivory knob; the instrument is, therefore, well adapted for demonstrating the inductions and reactions of electrical currents; when the ends of the secondary are disunited the sparks of the primary are large and brilliant;

when united, they are small and faint. But the secondary coil may be dispensed with altogether, and this is perhaps the best arrangement when the instrument is to be used for medical purposes. The writer constructed a machine of this kind some years ago, containing 100 yards of bell-wire surrounding a core of iron wires, battery contact being broken and renewed by clock-work, so that the frequency of the induced shocks could be regulated with the greatest regularity and precision; wires leading from either end of the coil, and attached to suitable binding screws on the stand of the apparatus, served to convey the extra current, in accordance with the principles laid down in 8 and 9. The frequency of the shocks was regulated by the clock-work mechanism, and the intensity by a water regulator—which ingenious and useful appendage to the medical coil was the invention of the Rev. F. Lockey. This was included in the circuit of coil, and by increasing or diminishing the distance between the wires, so as to interpose a greater or less thickness of water, the power of the shocks could be modified to any required degree, giving the operator such perfect command over the instrument as to enable him to apply this form of electricity to as delicate an organ as the eye, or to administer powerful shocks.

13.—The Induction Coil.

Up to about the year 1842, the only object sought by makers of electro-magnetic machines would seem to have been the production of shocks, and the regulation of their intensity and frequency. It was M. Masson who first directed attention to other static phenomena which the instrument was capable of developing; in that year he constructed, in conjunction with M. Breguet, an apparatus with which, though consisting of a single coil only, and that very imperfectly insulated,

he was able to obtain sparks in rarefied air of sufficient length to show the unequal heating powers of the two poles of the circuit; to charge a condenser, and to ignite platinum wire; these electricians were therefore the first to show that, by the process of induction, the electricity of the galvanic battery (dynamic) is converted into the electricity of the ordinary electrical machine (static).

In 1851, M. Ruhmkorff, an intelligent and well-known philosophical instrument maker in Paris, directed his particular attention to the more perfect insulation of the wire, which, after covering in the usual way with silk, he surrounded with a coating of gum-lac, and attached the ends to glass rods, rightly concluding that the wooden frame of the instrument, though sufficiently insulating for voltaic, was not so for static electricity. He moreover diminished the diameter of the coil, thereby, with the same quantity of wire, obtaining a greater number of convolutions; and he greatly increased the length of the secondary, extending it in some of his machines to the length of nearly six miles. Lastly, from a conviction that the magnetic current was more effectual in arousing an induced current than the mere coil, that is, that the secondary effects were referrible more to *magneto-* than to *volta-*electric induction, he gave in his coils a great development to the former, by introducing into the axis of the primary a large bundle of iron wires, which he found to acquire a much higher degree of magnetism than an equal weight of iron in the form of an iron bar. To interrupt the inducing current, he employed a simple piece of mechanism known as "Neef's" hammer, consisting of a small block of iron, which vibrated between the projecting end of the coil of iron wires and a small anvil connected with the primary coil, in such a way that when the anvil and hammer were in contact the current was *on*, but the

moment they separated it was *off*. It will be unnecessary to describe minutely this form of contact-breaker, as it has given place to other and far more efficient arrangements. With these improvements Ruhmkorff obtained effects which were at that time surprising; he not only got brilliant sparks between the terminals of the secondary wire, but between the wire itself and a body out of the circuit in communication with the earth; and he obtained a discharge, in a vacuous globe, of great brilliancy, the spark filling the balloon with that magnificent phenomenon, stratified light, about which we shall have more to say presently. These effects were greatly exalted in degree by interposing in the circuit of the primary a simple condenser, as recommended by M. Fizeau; brilliant and crepitating sparks in free air were now obtained, three-quarters of an inch long, and the shock was so violent, that it is stated by Du Moncel, that M. Quet, incautiously getting himself into the circuit, was knocked down, and so much injured as to be obliged to keep his bed for some time, nevertheless the battery only consisted of six elements. We are reminded by this story of the account given by Muschenbroek of the effects on himself of his first shock from a Leyden phial, which he declared deprived him of his breath, and made him ill for two days; it is, however, true that great care is necessary in experimenting with the induction coil as at present constructed, as an incautious contact with the secondary wire communicates a most disagreeable shock; though how M. Quet came to be so much affected, unless he wantonly placed himself directly in the circuit, we are at a loss to understand. Various forms are given by M. Ruhmkorff to his coil; the bobbin is sometimes arranged vertically, though generally horizontally, and the ends are backed up and supported by discs of glass or gutta percha, through which the wires of the secondary pass to their insulating pillars. The size of the

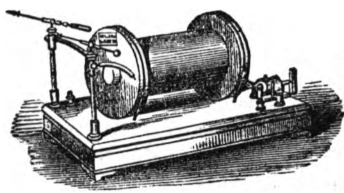
primary wire is about 0·078 in. in diameter; the secondary wire is the No. 28 of commerce; and the instrument is furnished with a commutator, for the purpose of reversing at will the direction of the current.

Shortly after Ruhmkorff's improvements were announced, Mr. Hearder exhibited one of his improved machines at the Royal Cornwall Polytechnic Society; it was six inches in length, and contained about a mile and a half of fine secondary wire; it was wound upon a hollow bobbin of wood, covered with gutta-percha, and having its centre large enough to contain the primary coil with its iron core. The secondary wire was covered with silk, and the layers insulated from each other with oiled silk and gutta-percha; it was provided with a condenser, gave sparks between the terminals more than one inch in length, and charged a Leyden jar containing three square feet of surface, so as to give a torrent of brilliant discharges between platinum terminals. For this instrument Mr. Hearder received the Society's first silver medal.

In September, 1856, Mr. Charles Bentley showed the writer a coil of his own construction, which gave sparks between terminals of silk-covered wire an inch and a half long, the primary being excited by five of Grove's cells. In building up this coil he used, as an axis, a hollow iron tube, nine or ten inches in length and half an inch in diameter; round this he arranged a considerable number of insulated wires, the same length as the tube, and sufficiently numerous to form a bundle of an inch and three-quarters in diameter. This core was insulated by being covered with six or eight layers of waxed silk. Thirty yards of No. 14 cotton-covered copper wire were then wound carefully round the iron core, forming two layers, which were then insulated from each other by eight thicknesses of waxed silk. The secondary wire consisted of 3,000 yards of No. 35 silk-covered copper wire, and the coils

which it formed were insulated by several layers of gutta-percha tissue; it was wound so as to leave a space of about one-sixteenth of an inch at either end of the coil beneath, so that it formed a cylinder with rounded ends—a form preferred, from its obviating the necessity of glass checks for keeping the wire in its place. The condenser, which was contained in a separate box, consisted of 100 sheets of tinfoil, 4 × 9 inches, each sheet of foil being placed between two sheets of carefully-varnished paper, and the alternate ends connected with appropriate binding screws.

FIG. 5.



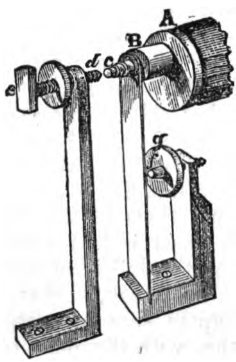
The induction coil, as now constructed by Mr. Ladd, which is shown in Fig. 5, and more conspicuously in the frontispiece, consists of the usual 'primary,' which is of covered copper wire, ·10 inch in diameter, or No. 12 wire gauge, wound into a coil of three thicknesses, enclosing a bundle of iron wires 1·8 inches in diameter; the ends of this fasciculus project ·7 inch beyond the gutta-percha ends, which are seven inches in diameter and ·6 inches thick; these gutta-percha discs are firmly fixed on the base-board of the machine, and serve both to support and to insulate the coil. The 'secondary' is a coil of No. 35 silk-covered wire, three miles long; it is very carefully wound round the primary in about thirty layers, each layer insulated from its neighbour by a sheet of gutta-percha. The total length of the coil is eleven inches, and its diameter, including the

velvet jacket, five inches. The ends of the secondary pass through one of the terminal gutta-percha discs to an insulated discharger, the arms of which move in ball-and-socket joints, so that the terminals may be separated any distance from one another up to about four and a half inches. The arm in connection with the wire proceeding from the *interior* of the coil is provided with an ivory handle, with which the arm may be moved; the other arm, in connection with the *exterior*, terminates in a brass knob; this must not be touched while the machine is in action, if the operator wishes to avoid a powerful and painful shock. One of the ends of the primary is brought out through the anterior and the other through the posterior gutta-percha disc, to two brass studs, from which they are conducted underneath the wooden base to the commutator and the contact-breaker. The wires from the battery (five pairs of Grove's arrangement, immersed platinum $5\frac{1}{2} \times 3$ inches), are attached to two binding screws, one on either side of the contact-breaker, as shown in the frontispiece. The condenser is conveniently placed in a box underneath the base of the instrument, to which it is firmly attached. It is composed of about fifty sheets of tinfoil, 18×8 inches, and between each sheet is laid a sheet of varnished paper; one-half of the foil is in metallic connection with each side of the break, so that when contact is broken the interrupted ends are respectively in metallic communication with the opposite coatings of the condenser.

The contact-breaker merits especial notice, as it is to the improvements introduced into this part of the apparatus that the surprising effects of the coils of the present day are in a great measure to be ascribed. In Ruhmkorff's original instrument, the interruption of the battery current was, as we have seen, effected by the rising and falling of a small iron hammer; this,

whilst it accomplished the general purpose of breaking and renewing battery contact, set up no resistance, the hammer being raised as soon as the iron core had received sufficient magnetism to enable it to attract a very small piece of iron, whilst the falling of the hammer on the interruption of the current was in no way influenced by the degree of magnetization of the iron core. The contact-breaker is now constructed by Mr. Ladd, with the object of giving the operator the means of setting up a greater or less resistance to the attractive force exerted by the magnetic iron core. This is accomplished by attaching the hammer to a stiff spring, placed vertically, as shown in Fig. 6, where A is

FIG. 6.



the disc of iron capping one end of the iron core; B, the iron hammer of the contact-breaker, surmounting a stiff spring attached to a brass stand screwed to the base-board of the instrument; *c* is a little projecting nipple, tipped with platinum; *d*, a corresponding little disc of platinum, soldered to the end of a screw, which passes through the top of a brass pillar, firmly screwed

down to the base-board; the distance between *d* and *c* can be regulated with the greatest nicety by the thumb-screw, *e*. Now, when *c* and *d* are in contact, and the commutator is turned on, the battery current is circulating round the primary coil, the fasciculus of iron wires becomes a more or less powerful magnet, according to the power of the battery; B is attracted to A, by which act *c* and *d* are separated; battery contact is hereby broken, and the effects of the induced current are obtained at the terminals of the secondary. But if the action of the contact-breaker ended here, it would be nothing more than Neef's hammer placed vertically; it will be seen, however, that by turning the screw *g*, the point *f* attached to its axis may be made to press with greater or less force on the spring supporting the hammer, thereby keeping *c* and *d* more or less firmly in contact, and necessitating a corresponding degree of magnetization of the fasciculus to part the platinum discs; when, however, this has been attained, contact with the battery is instantly broken, and the hammer is forced back with violence by the conjoint action of the spring and screw; *d* and *c* again come into contact, the iron core again becomes magnetic, A attracts B, and the battery current is stopped, *c* is again forced upon *d*, and so on. Now a degree of pressure may be exerted on the spring support of B by the screw *g* sufficiently great entirely to overcome the attractive force of A; under such circumstances the instrument is, of course, passive, but by gradually relaxing the tension at a certain point, the magnetic power of the core just overcomes the antagonistic force of the spring, and then it is that the most powerful inductive effects are obtained, evidently because then the fasciculus has received from the battery its maximum amount of magnetism, which it loses instantaneously by the interruption of the battery circuit, giving rise to a powerful

wave of induced static electricity in the secondary coil. The influence exerted by the resistance thus set up to the rupture of battery contact on the strength of the induced current is far greater than could have been anticipated. The instrument we have been describing gives between the terminals of the secondary, when the screw *g* is entirely relaxed, thin thready sparks, about 1½ inch long, but when the spring is strained to the utmost, brilliant flashes of fire, upwards of 4 inches long, pass continuously. The control which this form of breaker gives to the operator while performing experiments in which considerable variations in the power of the induced current are required, renders it of great value.

The Condenser.—The function of this very important part of the modern Induction Coil is by no means clearly understood. Fizeau, who suggested it, says, that it condenses and destroys, by a static effect, the electricity of tension or induction which gives rise to the extra-current in the induction wire, and which reacts on the induced current in the secondary wire in a direction contrary to that of the voltaic current. Faraday seems to have much the same opinion. He says:—"When the secondary current is interrupted, the inducing power of the primary current acts in its own wire to produce certain hurtful or wasteful results; the condenser takes up this extra power at the moment of time, and converts it to a useful final purpose upon principles belonging to static induction." Poggendorff's view is that the function of the condenser is to draw away the electricity of tension which, when the battery current is interrupted, accumulates at the two ends of the inducing coil, where it would otherwise be retained by the resistance of the air reacting on the fluid set in motion in the thin wire, and so diminishing its intensity. Hearder suggests, that at the moment of breaking the contact the induced current exhibits its

intensity at the points of separation by overleaping the interval; but if these two interrupted ends be in contact with the extended conductors of the condenser, a portion of this intensity may possibly be reduced by its being determined in the direction of the two conductors, which, by inducing upon each other, have their capacities for electrical charge considerably increased, and thereby act as capacious reservoirs, in which these intensities may expand and exhaust themselves. Whatever may be the true explanation of the *modus operandi* of the condenser, it is certain that it increases vastly the static effects of the induced current, although it does not increase the quantity of the electricity set in motion. Mr. Ladd fits up some of his coils with a simple arrangement for detaching the condenser; if this be done while sparks or flashes four inches in length are leaping between the wires of the discharger they immediately cease, and the terminals require to be brought within half an inch of each other before thin thread-like sparks can be made to pass between them.

14.—Effects of the Induced Current.

In making the following experiments, it is assumed that the operator is working with an instrument such as is figured in the frontispiece:—

Example 1.—The battery being well-charged—the zinc cells, with a mixture of one part of oil of vitriol and five of water, and the platinum cells with ordinary nitric acid—draw the ends of the discharger about three inches apart, and turn the commutator; brilliant zig-zag crepitating flashes will dart between the points, the length of which may be increased to four inches, and sometimes even more, by withdrawing the points gradually (take care *not* to touch the arm which has the brass knob); now bring the points to within about two inches of each other, and observe the

spark, it will be found split up into bundles, and to be surrounded with a sort of yellow-green atmosphere, which may be expanded into a mass of irregular violet-coloured flame by gently blowing it. The two parts of the induction-spark, viz., the point of light and the luminous atmosphere, may be completely separated by opposing to one of the electrodes another of a V-shape. By suitably regulating the distance of the extremities of the latter from the former, M. Serrot succeeded in establishing an atmospheric current, which carried the luminous atmosphere towards that branch of the V-shaped electrode which was more remote from the opposite pole. Under these circumstances the luminous atmosphere appeared only at this latter branch—the other branch receiving the ordinary spark. Du Moncel has also shown that of the two parts of the spark the luminous atmosphere only is affected by the magnet. Dr. P. L. Rijke has made experiments, from which he concludes that the point of light in the inductive spark is to be attributed to the re-compositions of the electric charges accumulated at the extremities of the secondary wire, while the luminous atmosphere is produced by the electric fluid contained in the parts of the wire nearer to its middle point. When the inductive wire is discharged, the electric charges of the two extremities first unite, and the spark is bright, while the charges of the parts nearer the centre, meeting with considerable resistance, require a sensible time, and the spark becomes altered, diminishing in illuminating power and increasing in volume.

Ex. 2.—While the 4-inch sparks are passing, remove the wire which connects the two binding screws on the left-hand side of the base of the instrument, thereby disconnecting the condenser; the sparks will immediately cease, and the wires will have to be brought within a half of an inch before they reappear, now very faint and thin; re-connect the screws, and the

flashes will reappear with their former length and brilliancy. If the spark from a Ruhmkorff coil be projected on a screen by the electric current, and the impression contrasted with that of the flame of a candle —in the former, two cones are seen to issue from the terminals instead of the single one of the latter, one being more powerful, and overcoming or beating back the other; and this effect is reversed as the direction of the current is reversed. In the voltaic arc there is a transmission of matter, principally from the positive (which is the more intensely heated) to the negative terminal; in the spark from the coil the dispersion is principally, and in some cases appears to be entirely, from the negative terminal, which is now the more intensely heated.

Ex. 3.—Attach to the terminals of the discharger two platinum wires, each about two inches long, and gradually approach them; the wire on the negative side will now become intensely heated, and will ultimately fuse; now turn the commutator, thereby changing the direction of the current; the same phenomenon will occur with the other wire; substitute for the platinum wires thin wires of iron, the negative wire will speedily begin to burn with brilliant scintillations; replace the iron by zinc, the negative wire will burn with a brilliant white light. This heating property may be taken advantage of to determine the direction of the induced current. While vigorous sparks are passing between the terminals, introduce a piece of paper, or a thin shaving of wood; either will be speedily kindled.

Ex. 4.—Attach iron filings to a large pane of glass, by means of a suitable varnish, and when dry place it between the terminals; flashes of light more than a foot in length may thus be obtained. Moisten a piece of cork, ten inches long and four inches wide, with dilute sulphuric acid, place the terminals upon it, first about

two inches apart; great heat will be set up on the line of discharge, which will vaporise the water, and the cork, becoming charred by the sulphuric acid, will begin to burn; now slowly separate the terminals, drawing one along the surface of the cork, in a zig-zag manner, the flame will follow it, charring the cork in its progress and leaving behind a line of light. In this way you may proceed from one end of the cork to the other, making a complete lake of fire, which has, in the dark, a very beautiful appearance. The best way of making the experiment is to lay the cork upon the table, and stick into one end a platinum wire in connection with the interior of the coil; a wire, leading from the exterior, is attached to a brass rod provided with a varnished glass handle, and to this a stout platinum wire; the operator directs the wire along the cork by this contrivance without the chance of getting a shock. If a sheet of silvered leather be substituted for the cork, it becomes brilliantly illuminated with a green coloured light; or if common leather be moistened with dilute sulphuric acid, it may be used instead of cork. It must be observed that both cork and leather, after having once been rendered conducting by acid, retain their conducting power for a long time after they have become dry.

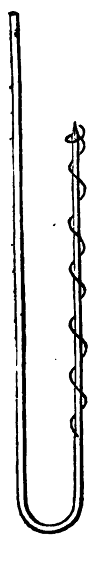
Ex. 5.—Separate the arms of the discharger beyond the striking distance; in the dark, brushes of light will be seen to dart from the positive electrode, and the negative will be illuminated by its characteristic star of light, also throwing off smaller brushes which re-curve over the wire.

Ex. 6.—In liquids of good conducting power no spark can of course be obtained, but in *non* or imperfectly conducting fluids short crepitating sparks pass. In *oil* these sparks have a greenish white colour; in alcohol they are red and crepitating; in oil of turpentine, and in bi-sulphide of carbon, they are very brilliant.

Pour some oil on the surface of water in a glass vessel; introduce a wire covered with gutta percha, and proceeding from the interior of the coil, underneath the water, just below the oil, and plunge a protected wire from the other extremity within striking distance in the oil; strong crepitating sparks are obtained, and hydrogen gas is liberated, which burns on the surface of the liquid.

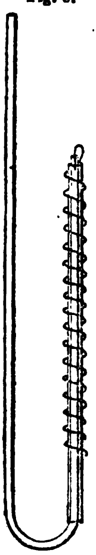
Decomposition of Gaseous Compounds.—When the spark-current from the induction coil is sent through ammonia, it exhibits a violet light, surrounded with a blue edge. At first the mercury over which the gas is confined falls rapidly, the rate of expansion diminishing with the progress of the decomposition; in five minutes the decomposition of a moderate volume of ammonia is accomplished. The original volume is then doubled; the spark current exhibits the pure violet light characteristic of hydrogen, and water injected into the tube produces no diminution of volume. The coil thus becomes a valuable instrument for demonstrating the composition of this interesting gaseous alkali in the lecture room. For the introduction of the spark current through this and other gaseous compounds, the simple apparatus shown in Fig. 7 was contrived by Buff and Hofmann. A fine platinum wire is fused into the shorter limb of a thin U-shaped glass tube, and filed off so as scarcely to project beyond the glass. At a distance of a few millimètres from the platinum pole thus obtained, the loop of a second platinum wire is thrown over the tube, and the wire wound round the tube until it nearly reaches the bend. The tube is then filled with mercury, and the shorter limb introduced into the graduated gas-tube inverted

Fig. 7.



over mercury in a deep cylinder trough. The pole wires of the induction coil being now introduced, the one into the open end of the U-tube filled with mercury, and the other into the mercury of the cylinder trough, the spark current may be established or interrupted at will, by either depressing the U-tube until the outer platinum wire reaches the mercury surface, or by lifting it so as to break contact. Occasionally Buff and Hofmann effected the decompositions by incandescent coils of iron or platinum, or by the electric arc. For experiments of this nature, both limbs of the U-tube remain open. The iron or platinum wire is inserted into the shorter limb, and then coiled downwards round the tube, as shown in Fig. 8. Since the powerful heat emitted from the coil is apt to crack the U-tube, it was found convenient to surround the latter with a somewhat wider glass tube, which separates it from the incandescent coil. The U-tube, as in the previous case, is filled with mercury, and the pole wires of the battery are adjusted in a similar manner. By depressing the U-tube until the lower end of the coil dips into the mercury, the coil may be readily heated; by raising the end to a proper height above the level of the mercury in the tube, the *arc* may be conveniently adjusted. Amongst the results obtained by these chemists are the following:—Cyanogen was not decomposed by the spark-current, but perfectly by electrically incandescent wires, and more rapidly by the electric light, 50 volumes of the gas leaving, after half an hour, 50 volumes of pure nitrogen; nitrous oxide was slowly decomposed by the spark-current into nitrogen and oxygen; rapidly by incandescent iron, with the formation of sesquioxide of iron and a volume of

Fig. 8.



nitrogen equal to that of the original gas. Nitric oxide was decomposed slowly by the spark-current, rapidly by the incandescent iron coil, the iron burning with splendid scintillations; the residual volume of nitrogen was one-half the original volume of gas. Through dry carbonic oxide the spark-current passes with a blue light, but without effect, nor was this gas decomposed either by the incandescent coil or by the electric arc. Carbonic acid was decomposed by the spark-current into carbonic oxide and oxygen; the mixture then exploded, reforming carbonic acid; unfortunately the decomposition is too slow for a lecture experiment; the colour of the spark in the gas is violet. Marsh gas was partially decomposed by the spark-current, ten volumes of the gas becoming, in half an hour, eighteen volumes, and the colour of the spark changing from pale blue to violet. Olefiant gas was decomposed by the spark-current, which traversed the gas with a pale red light into carbon and hydrogen; after about twenty minutes, seven volumes of the gas became 12½; had the decomposition been perfect, the volume should have been doubled. Sulphuretted and phosphoretted hydrogen were both rapidly decomposed by the spark-current, the former with the deposition of sulphur, the latter with that of phosphorus, in the form of a brown powder. These results are sufficient to show what a powerful, elegant, and useful agent of gaseous analysis the Induction Coil is likely to become.

Ex. 7.—Place several lighted spirit-lamps side by side, between the terminals of a universal discharger, connected with ends of the coil; separate the points twelve inches, the sparks will flash through the flames; with a small coil, not capable of giving sparks more than one inch long in cold air, sparks four inches long may easily be obtained through flame.

Ex. 8.—Connect the terminals of the coil with the inner and outer coatings of a large Leyden phial, and

separate the points of the discharger about ¼ of an inch, turn on the commutator, whereupon an extremely brilliant discharge will take place between the points, assuming quite the character of the ordinary Leyden discharge; the noise of this continuous discharge is too great to be borne long without discomfort. "I have never," writes Mr. Grove, who first described this magnificent experiment, "witnessed such a torrent of electrical discharges; it is curious to see the absorption, so to speak, of the voltaic power by the Leyden battery. When the maximum effect for a given Leyden jar has been passed, the contact-breaker shows by its sparks the unabsorbed induced electricity, which now appears in the primary wire; an additional jar acts as a safety-valve to the contact-breaker and utilizes the voltaic power, and so on."

Ex. 9.—Introduce a card between the terminals, arranged as in the last experiment; it will be perforated precisely as with ordinary electricity. Mr. Grove has proposed to count the discharges, by causing a piece of paper to pass with a given velocity per second between the discharging points, and the number of perforations thus made per second may be registered. Mr. Hearder has invented a very ingenious apparatus for carrying out this idea, with which he has endeavoured to compare the effects of the coil with that of an electrical machine, by estimating the amount of glass surface necessary to be rubbed to produce effects equal to those of the coil. The rapidity of the discharges will depend upon the nature of the interrupting spring employed in the coil, and as many as 100 to 200 per second may be obtained.

Ex. 10.—Substitute for the Leyden jar a "fulminating pane," consisting of a square of common window glass, about 15 inches square, coated on either side with tin foil; attach to one of the coatings a band of foil, of sufficient length to fold over the edge of the glass and

touch the other coating. If this band be wound round a glass rod, the two coatings may be brought within any required distance of each other, by simply winding or unwinding the foil; adjust to the maximum striking distance, and turn the commutator; the discharge now amounts to a positive *roar*, the vividness of the light of which may be appreciated by darkening the room.

Ex. 10a.—Fix a piece of platinum wire horizontally across the ball of a Leyden jar, and bring the secondary terminals respectively near its ends; two interruptions are produced in the secondary circuit, the sparks at which are like each other and equal in quantity of electricity, for the jar as yet forms only an insulating support; now connect either terminal by a wire with the outside of the jar; the spark on that side assumes a bright loud character, but ceases to fire gunpowder, or wood, or paper; and no one would suppose at first, what is the truth, that there is the same electricity passing in one as in the other. The effect of the jar is not to vary the *quantity* of electricity, but the *time* of its passage. That electricity, which, moving with comparative slowness through the great length of the secondary coil, produces a spark having a sensible duration (and, therefore, in character like that of a Leyden jar passing through a wet thread) is, when the jar is used, first employed in raising up a static induction charge, which, when discharged, produces a concentrated spark of no sensible duration, and therefore much more luminous and audible than the former. If one of the secondary terminals be connected with the outside of a Leyden jar, and the other be continued until near the knob or wire connected with it, a soft spark appears at such intervals for every successive current in the primary circuit. This spark, however, is *double*, for the electricity thrown into the jar at the moment of induction is discharged back again at the same place the instant the induction is over; the first

discharge heats and prepares the air there for the second discharge, and the two are so nearly simultaneous as to produce the appearance of a single spark to the unaided eye.—(*Faraday.*)

Ex. 10b.—The difference in the thermal properties of the induced current, with and without the intervention of the Leyden jar, is well shown by the following excellent experiment, devised by Hearder:—Connect a thermo-electrometer and a Lane's discharging electrometer with the terminals of the coil. Upon an adjoining table place a disc of wood, covered with tin-foil, exposing a flat surface of five or six square feet, and connect it also with one terminal of the coil. Take a second similar disc of wood, covered with tinfoil, and suspend it over the first one by means of a string passing over pulleys, in a frame so constructed as to admit of the second disc being raised to the height of five or six feet above the lower one. Connect this disc, by means of a flexible wire, with the other terminal. By this arrangement the two terminals have virtually their conducting surfaces increased, and the sparks consequently are much brighter, though the thermo-electrometer is unaffected. If now the upper coated disc be gradually lowered, the sparks rapidly increase in power, and when they are within three or four inches of each other they assume the character of the discharges of a Leyden jar, and the thermometer begins to be affected. As the discs are gradually lowered still further, their faces being kept parallel to each other, the sparks become still louder, and the thermometer rises 15° or 20°, thus acting as coatings to a charged plate of air. On removing the upper plate these effects subside, and the spark reassumes its original character.

Ex. 11.—If a Leyden jar, coated with detached, diamond-shaped pieces of tinfoil inside and out, be connected with the terminals, it will be brilliantly illuminated during the whole time that the machine is in

action. The best effects are obtained when the coatings are connected by two or three broad bands of tinfoil passing over the edge of the jar. If this be tolerably large, and if the rows of diamonds be so placed inside the jar that their horizontal points nearly touch one another at the centres of the circular holes cut in the diamonds of the outside, the discharge is exceedingly beautiful in a darkened room, far more so than with a common electrical machine.

Ex. 12.—If the discharges from a Leyden phial be made to pass over a lump of white sugar, or a crystal of alum, they will be beautifully illuminated; if through a fine iron two or three feet long, suspended by silk threads in a festoon, sparks, accompanied with brilliant scintillations, occur at every link.

Ex. 13.—Pass the discharge through a small heap of gunpowder on the table of the universal discharger; it will be thrown about in all directions, but not ignited; now interpose a piece of wet string in the portion of this circuit between the discharger and the jar, the gunpowder will immediately be inflamed. This is precisely what occurs with ordinary electricity.

Ex. 14.—The following experiment is one of the most beautiful that can be made with the Induction Coil. It is called the "Cascade," and was thus described by Mr. Gassiot, who originated it:—Coat a beaker, about 4 inches deep by 2 inches wide, with tinfoil, so as to leave 1½ inch of the upper part naked. On the plate of an air-pump is placed a glass plate, and on it the beaker, covering the whole with an open-mouthed glass receiver, on which is placed a brass plate, having a thick wire passing through a collar of leathers; the portion of the wire within the receiver is covered with a glass tube; one end of the secondary coil is attached to this wire, and the other to the metallic plate of the pump. As the vacuum improves the effect is truly surprising: at first a faint, clear, blue light appears to

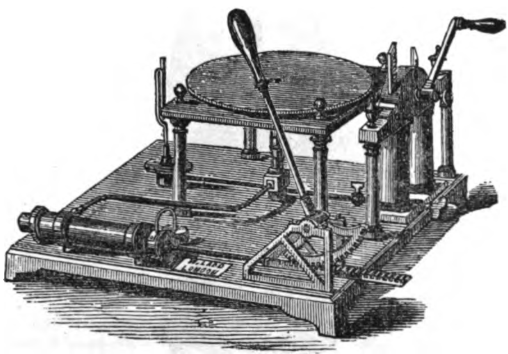
proceed from the lower part of the beaker to the plate; this gradually becomes brighter, until by slow degrees it rises, increasing in brilliancy until it arrives at that part which is opposite, or in a line with, the inner coating, the whole being intensely illuminated; a discharge then commences from the inside of the beaker to the plate of the pump, in minute but diffused streams of blue light; continuing the exhaustion, at last a discharge takes place, in the form of an undivided continuous stream, overlapping the vessel, as if the electric fluid were itself a material body running over. If the position of the beaker be reversed, by placing the open part on the plate of the air-pump, and the upper wire either in contact with, or within an inch of, the outside

FIG. 9.

of the vessel, streams of blue lambent flame appear to pour down the sides of the plate, while a continuous

discharge takes place from the inside coating. On turning the commutator, so as to reverse the current, the cascade appears to flow upwards instead of downwards. This truly magnificent experiment has been arranged by Mr. Ladd so as to dispense with the trouble of exhausting the receiver on each occasion. Fig. 9 (see page 42) shows the apparatus. The cup, or beaker, is not coated either inside or outside with tin-foil, but the wire through which the induced current is passed reaches to the bottom of the glass, and terminates in a gilded disc. The receiver is permanently exhausted by an excellent pump, as shown in Fig. 10,

FIG. 10.

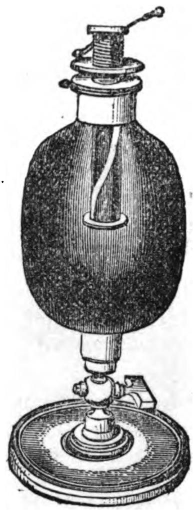


it having been first, as well as the cap, firmly secured by cement. It is then screwed on to a stand, and thus rendered permanently portable.

Ex. 15.—De la Rive describes the following experiment in illustration of his theory of the Aurora Borealis :—Place the pole of a powerful electro-magnet underneath the surface of mercury connected with the negative pole of a powerful voltaic battery; bring over and near it the positive pole armed with a charcoal

point; a voltaic arc is formed, and the mercury is agitated above the magnet; luminous currents rotate round the pole, throwing out occasionally brilliant rays. This phenomenon of the rotation of electric light round a magnetic pole is exhibited in a most superb manner by the apparatus (Fig. 11). Into the brass cap of a

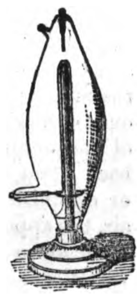
FIG. 11.



large globular or egg-shaped glass receiver a soft iron bar, surrounded with a coil of covered copper wire, is firmly fixed; the receiver is then exhausted. On sending the induced current through the vacuous receiver, a splendid band or riband of purple light makes its appearance, which immediately commences rotating round the iron rod, when that is converted

into an electro-magnet by sending the current from a small voltaic battery through its surrounding coil; on turning the commutator, so as to change the direction of the induced current, the direction of the rotation changes also. In this truly magnificent experiment electric light takes the place of the conducting wire in Faraday's discovery, mentioned in page 4. This experiment may be made more simple with the little apparatus shown in Fig. 12, consisting of a small

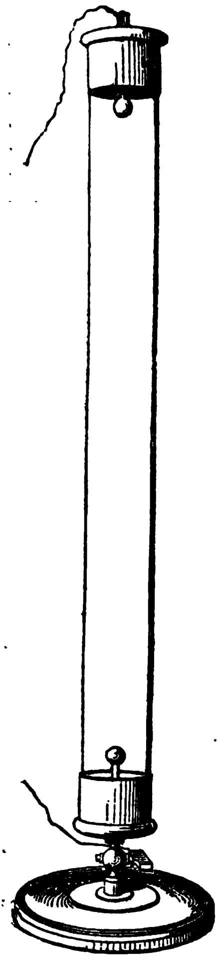
FIG. 12.



iron rod, enclosed air-tight in a small receiver which is exhausted; the iron rod is surrounded with a glass tube, round which there passes, towards the bottom, a metallic ring attached to a wire which passes through the receiver; a wire is also sealed into the top of the glass, and through these wires the discharge is made to pass; the riband of purple light instantly makes its appearance, and begins to rotate round the iron rod, on placing the receiver on one of the poles of a powerful permanent steel magnet or a small electro-magnet.

Ex. 16.—Exhaust a tube, such as shown in Fig. 13 (see p. 46), which may be from two to seven feet long, and from

Fig. 13.



1½ to 3 inches in diameter, having previously connected the wires at each end with the terminals of the coil. As the exhaustion proceeds, a splendid Aurora Borealis fills the tube with corruscations, and as the vacuum gets more perfect a broad crimson riband is obtained, extending throughout the entire length of the tube. Now turn the stop-cock very gradually, so as to admit a very small quantity of air, the effect of which is instantly seen by the disappearance of the riband and the re-appearance of the corruscations; but these gradually die out as the air enters. A few strokes of the pump, however, bring them back again, and thus, by increasing or diminishing the density of the air, the appearance in the tube may be made to undergo corresponding variations.

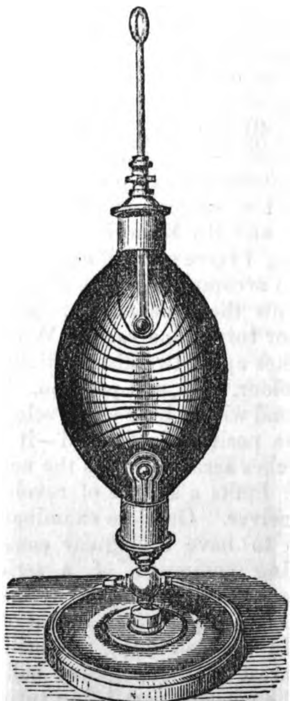
Stratifications in Electrical Discharges in Vacuo.—The striated condition of the electrical discharge in vacuo under certain conditions, was first announced by Mr. Grove, in a communication to the Royal Society, 7th January, 1852. The following was one of his first experiments:—A small piece of perfectly dry phosphorus was placed in a platinum capsule on the lower ball of the electric egg. To keep the receiver dry, a stick of caustic potash was suspended in a tube

from the upper wire; the exhaustion was then made as perfect as possible, when the crimson light became gradually furrowed with beautiful stratifications through a length which may be extended to 12 inches, and when once obtained, the experiments may be stopped, and after 20 minutes or more, resumed with more brilliancy than before. Mr. Grove afterwards found that the transverse dark bands could be produced in other gases when much attenuated, probably in all, and he thought the reason why they are more easily seen in phosphorus vapour is that, all the oxygen having been consumed, a better vacuum is formed. About the same time, Ruhmkorff noticed similar phenomena in an alcohol vacuum, and the subject engaged the attention of Masson, Quet, and Du Moncel.

Ex. 17.—Fig. 14 (see p. 48) is copied from the work of the last-named accomplished electrician, and very correctly represents the appearance presented in alcohol, wood, spirit, or turpentine vacua. When the poles are five or six inches apart, two distinct lights are produced, differing in colour, form, and position. That round the negative ball and wire is blue—it envelopes it regularly; that round the positive is fire-red—it adheres to one side and stretches across towards the negative, and has for its lateral limits a surface of revolution about the axis of the receiver. On close examination this double light is seen to have a singular constitution; it is stratified, being composed of a series of brilliant bands, separated from each other by dark bands. In a good vacuum, the appearance is that of a pile of electric light. In the red light, the brilliant bands approaching nearest to the negative ball have the form of capsules, the concave part being turned towards the ball; their position and figures are sensibly fixed, so that it is easy to see that there is a solution of continuity in passing from one to the other. The extreme capsule does not touch the violet light of the

negative pole, being separated from it by a dark band, greater or less according to the nature and perfection of the vacuum, that with spirit of turpentine giving

FIG. 14.



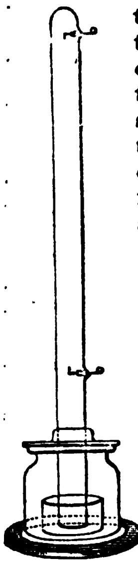
the greatest. It was found by M. Quet, that when a galvanometer was interposed at the circuit, no current was indicated as passing through the electric egg till

the exhaustion was tolerably good, and the light continuous; the needle then became permanently deflected. A light, though less brilliant, may be obtained from one pole only, that of the exterior wire of the secondary, which possesses electricity of the highest tension; and if the vacuum be very good, this light may be made to bifurcate by placing the finger against the outside of the glass. If currents from two coils be made to circulate in opposite directions through the receiver, the red light disappears from the positive pole, giving place to a blue light—the positive and negative lights are now the same. The same occurs when a resistance is introduced into the induced circuit, as, by interposing a condenser between one of the poles and one of the balls of the egg. A uniform blue light is thus obtained round both balls, which, with a good exhaustion, may be stratified.

Discharge in Torricellian Vacua.—The conditions necessary to enable the experimentalist to produce the phenomena of striæ or band discharge, have been stated to be:—1st. That the vacuum in the receiver should be as perfect as the air-pump can make it; 2nd. That care should be taken to absorb all trace of moisture; 3rd. That means should be used to introduce the vapour of naphtha or phosphorus, or other similar substances. In the barometrical vacuum, previous to the researches of Mr. Gassiot, detailed in the Bakerian Lecture (March 4, 1858), no striæ had been observed, the inductive spark being white and filling the whole tube; by making these vacua, however, with great care, Mr. Gassiot has succeeded in obtaining stratifications very distinct and well defined.

Ex. 18.—Into the glass tube (Fig. 15) are sealed two platinum wires about 18 inches apart; the tube itself is 28 inches long, and about five-eighths of an inch internal diameter; it is cemented into a brass plate, and when carefully filled with boiled mercury is placed on the open

Fig. 15.



mouth of a receiver on the air pump, the lower part of the tube being at the same time immersed in a basin of mercury; by this arrangement the length of the discharge could be regulated from one-sixteenth of an inch to 18 inches, either suddenly or very gradually, by allowing the air to enter into the receiver, or by exhausting it with the pump; the vacuum is never perfect, a very minute bubble of air always remaining; the stratifications are, however, very distinct when the discharge traverses the full length of 18 inches. In this experiment a single cell of the battery may be used to excite the coil, and the condenser need not be used. If the discharge be made constantly in the same direction, the upper wire being negative, the upper portion of the tube, as far down as a line drawn even with the end of the wire, becomes covered with platinum in a minute state of division; when this deposit is examined by transmitted light it is transparent, presenting to the eye an extremely thin bluish-black film; but by reflected light, either on the outside or inside, it has the appearance of highly-polished silver, reflecting the light as from the finest mirror. If the upper wire be made positive, and the lower negative, as soon as the mercury ascends above the negative wire a beautiful lambent bluish-white vapour appears to rise, while a deep red stratum becomes visible on the surface of the mercury; as the mercury ascends in the tube the stratified discharge from the positive wire collapses, giving the appearance of a compressed spiral; on exhausting, the mercury descends in the tube, and the stratification expands as if the pressure on a spiral spring had been removed.

In the course of his experiments on the inductive discharge through Torricellian vacua, Mr. Gassiot found a great want of uniformity in different tubes prepared in precisely the same manner; in some, no stratifications at all could be obtained, the discharge being clear, bright, and white; in others, the discharge was a wavy line unaccompanied with striæ; in others the stratification was confused and indistinct, while in others it was clear and well-defined. He therefore prepared some tubes by the non-boiling process, first proposed for filling barometer tubes by the late Mr. Welsh, of the Kew Observatory, (for an account of which see Phil. Trans., vol. 146, p. 507,) and with these he obtained clear, well-defined, and distinct bands, not only with the Induction Coil but with the ordinary electrical machine. The important feature in Mr. Welsh's method of filling barometer tubes is the perfect cleansing and drying of the tubes before the introduction of the mercury, by sponging with whiting and spirits of wine.

If the hammer of the contact-breaker be removed, and one of the terminals of the primary firmly fixed to a bright copper plate having a sharp edge, and the circuit completed by steadily pressing the end of the other wire on the plate, using one or two cells to excite the primary, no trace of any discharge will be perceived in the tubes; but if a sudden break of the battery circuit be effected, by bringing the wire quickly across the sharp edge of the plate, the stratifications immediately appear in the tube in a very distinct and beautiful manner; the more sudden the break, the more distinct will be the effects, and by using eight or ten cells they are distinctly visible on making contact. Contact with the battery may be also made and broken by dipping the wires in mercury. That the effects on making should not be equal to those on breaking contact, will be readily understood by considering that in the Induc-

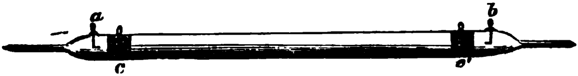
tion Coil the inductive effects are principally due to the electro-magnetic condition of the iron core, and that while the iron wires require a certain time to reach their maximum power, they lose their magnetism instanter when contact is broken, provided the iron be very soft, and therefore the more suddenly the contact is broken, the more intense will the discharge appear in vacuo.

In experimenting with vacuous tubes, the operator should always pass the current in the same direction as the emanation of the platinum particles, and the consequent deposit on the glass only takes place from and around the negative wire, the positive end of the tube remaining clear and bright.

When the discharges of two separate coils were passed, by means of four platinum wires, through the same tubes, Mr. Gassiot found no signs of interference, the separate stratification of each coil remaining visible, although producing a degree of confusion from their interposition; he found also that the stratifications were very powerfully affected by the magnet, when the discharge is passing from wire to wire; if a horse-shoe magnet be passed along the tube, so as alternately to present the poles to different contiguous positions of the discharge, it will assume a serpentine form, in consequence of its tendency to rotate round the poles in opposite directions, as the magnet in this position is moved up and down the side of the tube.

Two Distinct Forms of Stratified Electrical Discharge.—Ex. 19. These are illustrated by employing the simple tube shown in Fig. 16, which is 38 inches long,

FIG. 16.



and is exhausted by Mr. Welsh's process; the wires,

a b, are 32 inches apart; *C C'* are moveable coatings of tinfoil, two inches long, wrapped round the tube. When the discharges from an Induction Coil are made from wire to wire, the stratifications appear as already described; and if the tube be placed in a horizontal position over the pole of a magnet, the stratifications evince a tendency to rotate as a whole in the direction of the well-known law of magnetic rotation; but when the discharge is made from coating to coating, or from one wire to one coating, an entirely new phenomenon arises, the stratifications have no longer a tendency to rotate as a whole, but are divided. If the tube be now placed between the poles of a powerful electro-magnet, one set of stratifications are repelled from, and the other attracted towards, or within, the bent portion of the magnet; when the tube is placed on the north pole the divided stratifications arrange themselves on each side of the tube, changing their respective positions when placed on the south pole, but in all cases each set of stratifications are concave in opposite directions. Mr Gassiot, to whom this singular experiment is due, designates these discharges as the direct or conductive and the reciprocating discharge. The former is that which is visible when taken from two wires hermetically sealed in a vacuum tube. This discharge has a tendency to rotate as a whole round the poles of a magnet; the latter is that which is visible in the same vacuum when taken from two metallic coatings attached to the outside of the tube, or from one coating and one wire. The induced charge is divisible by the magnet into two sets of stratifications, each set having a tendency to rotate round the pole of the magnet in opposite directions; the character of the electrical discharge, with relation to these two forms, can always be determined by the magnet.

Discharge in Different Rarefied Media.—In dry hydrogen gas no discharge takes place from the

induction coil, if the wires be separated in the tube beyond the striking distance in air; but when the gas is rarefied by the air-pump, the discharge first appears as a wavy line of blueish-grey colour; on continuing the exhaustion, and assisting the rarefaction by heating gently, the tube becomes filled with a luminous discharge to within about one inch of the negative wire; the stratifications appear gradually increasing in width as the vacuum becomes more perfect; and if care be taken to continue the pumping so as to prevent air being introduced, the tube can be sealed without the stratifications showing the slightest appearance of redness. If the extremity of a vacuum tube be presented to the prime conductor of an electrical machine, or to one of the terminals of an induction coil, a spark can be taken, and the glass will be perforated. The perforation is extremely minute, but sufficient, under the pressure on the vacuum, to admit air or gas; but, so slowly does the air or gas enter, that the experimentalist is enabled to note the gradual change which takes place during the progress of the discharges of the coil. Mr. Gassiot connected the extremity of a vacuum-tube, after perforation, by means of a tight-fitting gutta percha tubing, to a glass cylinder containing fused chloride of calcium, through which air, hydrogen, oxygen, or nitrogen was permitted to pass into the vacuum. The result of many repeated experiments showed that with hydrogen and oxygen no change in the colour takes place; with air or nitrogen the colour of the stratifications changes from bluish grey to fawn, and ultimately to a deep red tinge; and, during this addition of gas or air, the cloud-like stratifications gradually close, becoming narrower and narrower until they are utterly destroyed, passing to a mere luminosity filling the entire tube, and finally into the wave discharge.

The writer can confirm this description of the appearances presented when atmospheric air slowly

makes its entrance into a vacuous tube. The experiment is interesting and instructive, although somewhat costly, and not one which amateurs will be very likely to repeat. On a late occasion, whilst exhibiting to an audience the beautiful stratifications in a carbonic acid vacuum, in a tube such as exhibited in Fig. 16, the striæ suddenly disappeared, and the discharge, which was at first nearly white, became first grey, then bluish grey, and finally resolved itself into a riband of red light; this continued for some time, and then died away, and the discharge ceased to pass. On examining the tube, a very minute crack was observed proceeding from one of the platinum wires, probably the negative, which had become too highly heated. Too much battery power had been employed. The accident is related as a warning to those inexperienced in those experiments to be very careful not to excite the coil too strongly whilst passing the inductive discharge through the vacuous tubes. Two cells of Grove will be found amply sufficient, and even with this power it will be well to relax somewhat the spring of the contact-breaker.

Influence of Temperature.—The following results were obtained by Professor Faraday and Mr. Gassiot, in Torricellian vacua, through a range of upwards of 700 deg. Fahr. A vacuum which gave good cloud-like stratifications, exhibited no change when the temperature was lowered to $+ 32°$; but at a temperature of $— 102°$, obtained in a bath of ether and solid carbonic acid, all traces of stratifications were destroyed, and in this state the red or heated appearance of the negative wire disappeared, the discharge filling the entire vacuum with a white luminous glow. On the temperature being raised by the application of heat to the mercury, the stratifications re-appeared. When the mercury was boiled, indicating heat of up-

wards of + 600° Fahr., the stratifications were all destroyed, but in this case the discharge passed along the mercury as it condensed in the cooler part of the tube. When the mercury was frozen the stratifications disappeared, and the discharge did not illuminate the entire length of the tube, but merely the terminals. In this state, when a horse-shoe magnet was brought near the tube, the cloud-like stratifications immediately appeared from the positive wire, very distinct and large, but not so clearly separated as when the tube was at its normal temperature.

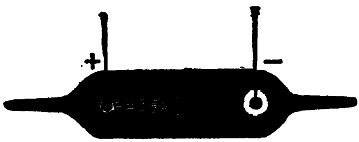
Discharge in Carbonic Acid Vacua.—At the suggestion and with the assistance of Dr. Frankland, Mr. Gassiot prepared tubes in which the carbonic acid with which they were filled was absorbed, after exhaustion by a good air pump, by caustic potash. In vacua obtained by this process, the discharge from an Induction Coil is first in a white wave line, strongly affected by the magnet, or by the hand when placed on the tube. In this state the discharge does not generally present the stratified appearance, or if present the stratifications are only near the positive terminal. After a time, however, as the carbonic acid becomes absorbed by the potash, the stratifications gradually appear more clearly defined; they assume a conical form, and, lastly, the cloud-like appearance of the best mercurial vacua. After this, under some conditions, the stratified appearance entirely ceases, the whole length of the tube being filled with faint luminosity. When in this state, if the outside of the tube be touched with the finger, pungent electrical discharges arise, and sparks one-eighth of an inch in length can be elicited. The appearance presented when the discharge was sent through a tube four inches long, the wires which were one inch apart being terminated with gas-coke balls one-eighth of an inch in diameter, was as shown in

Figs. 17 and 18. On the positive coke, minute luminous spots were visible; the negative coke was surrounded

FIG. 17.

with a brilliant glow. At intervals, apparently by some energetic action, flashes of bright stratified light

FIG. 18.



would dart through the vacuum, but by carefully adjusting the contact-breaker, the discharge could be made to pass, without to the eye affording any appearance of an intermittent discharge.

A large egg-shaped glass vessel, the globular portion being 18 inches long and 7 inches in diameter, was made under Mr. Gassiot's direction; the wires were 22 inches apart, and caustic potash was placed in the narrow end. It was filled with carbonic acid, and exhausted by Dr. Frankland's process. A portion of the potash being heated by a spirit-lamp, in about two months the discharge assumed, in a very marked manner, the character of large distinct clouds, most clearly and separately defined; they were strongly affected by induction as the hand approached the globe, presenting a very striking appearance. There was a slight tinge of red, showing that a very minute quan-

tity of air remained; the cloud-like stratifications extended to the entire diameter of the vessel.

Fig. 19 is another form of apparatus. The tube is 14 inches long and about one inch internal diameter;

FIG. 19.

it has a glass division in the centre, perforated with a hole about one-eighth of an inch in diameter. The striæ on the negative side are here very clearly defined, while on the positive side they are indistinct. When the discharge has assumed the cloud-like appearance, the aperture in the diaphragm only affects the discharge by contracting the cloud which passes immediately through it. That the passage of the discharge depends upon the presence of matter, and the stratifications probably to pulsation, or impulses of a force on highly attenuated matter, seem to be rendered probable by the fact that, in some of Mr. Gassiot's tubes, in which the absorption of the carbonic acid by caustic potash contained in one end of the tube was complete, no discharge could be made to pass; the same was the case with other tubes containing, besides caustic potash, fused chloride of calcium, sulphur, and selenium.

Luminous Discharge of Voltaic Batteries when examined in Carbonic Acid Vacua.—When the discharge from a water-battery of 3,520 cells was sent through carbonic acid vacua tubes, stratified discharges, similar in character to those of the inductive coil, were obtained, and Mr. Gassiot found that whenever the potash in any of the tubes was heated the discharge entirely ceased. From the steady deflection of the galvanometer needle placed in the circuit, the discharge had the appearance of being continuous, but closer examination showed them to be intermittent.

From a Daniell's battery, consisting of 512 series of elements, no stratified discharge could be obtained through any of the vacuous tubes, but in one a brilliant glow was observed round the negative, and a trifling luminosity round the positive coke ball terminal. With 400 series of Grove's nitric acid battery, each cell carefully insulated, the most magnificent effects were obtained. The different vacuum tubes used were introduced between one of the copper discs of a micrometer-electrometer and the battery, as also a galvanometer. By this arrangement the circuit could be gradually completed without any risk of disarranging the apparatus, and the spark discharge obtained before the copper discs of the micrometer-electrometer came into contact. Dr. Robinson thus describes an experiment which he witnessed in Mr. Gassiot's laboratory, with a tube 24 inches long and 18 in circumference, one terminal being a copper disc, 4 inches in diameter, and the other a brass wire:—"On the completion of the current, the discharge of the battery passed with a display of magnificent strata of most dazzling brightness. On separating the discs, by means of a micrometer screw, the luminous discharges presented the same appearance as when taken from an induction coil, but brighter. On the copper plate in the vessel there was a white layer, and then a dark space about an inch broad; then a bluish atmosphere, curved like the plate, evidently three negative envelopes on a great scale; when the plate was positive the effect was comparatively feeble." Between coke terminals a stream of light, of intolerable brightness, was presented, in which strata could be observed through a plate of green glass; this soon changed to a sphere of light on the positive ball, which became red hot. On heating the caustic potash, the discharge again burst into a sun-like flame, subsequently subsiding into three or four large strata, of a cloud-like shape,

but intensely bright. The appearances presented when the potash was heated are depicted in Figs. 20 and 21. Mr. Gassiot arranged the apparatus

FIG. 20.

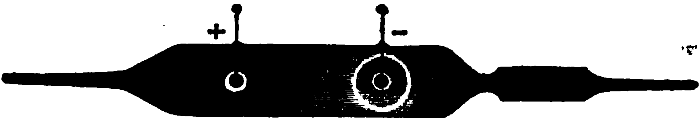
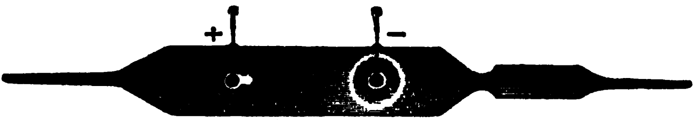


FIG. 21.



by attaching gold-leaf electroscopes to both terminals, and introducing the galvanometer so as to enable him to examine more carefully the action that would take place when the potassa was heated. On heating the potassa, the fine negative glow was developed; the leaves of the electroscope did not close, but as the negative glow increased, the needle of the galvanometer was suddenly deflected, immediately returning to zero. As more heat was applied, a small globe of light appeared on the positive ball, and the needle was gradually deflected 40° to 50°. On withdrawing the lamp as the potash cooled, the positive glow disappeared, the needle of the galvanometer receded, the glow on the negative remaining more or less brilliant; this action and reaction alternating as the heat of the lamp was applied to or withdrawn from the potash. When the heating of the potash was further increased, four or five cloud-like and remarkably clear strata came

out from the positive ball, Figs. 22 and 23, and these were quickly followed by a sudden discharge of the

FIG. 22.

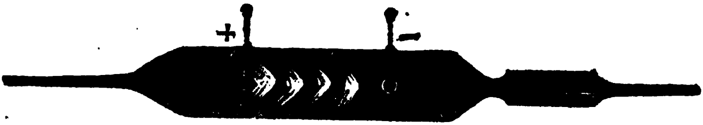
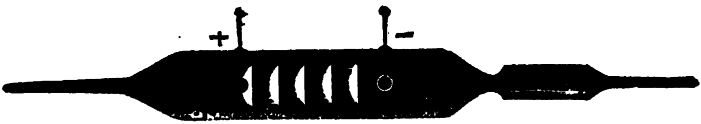


FIG. 23.

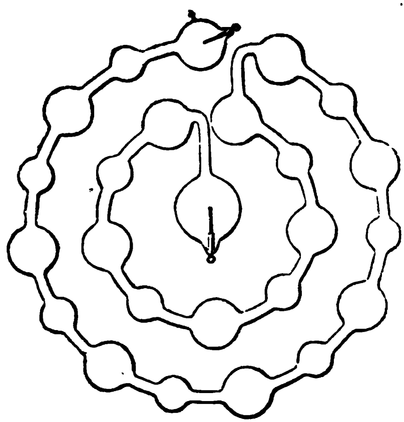


most dazzling brightness, which remained for several seconds. The needle of the galvanometer was suddenly and violently deflected. By these and many other equally striking experiments, Mr. Gassiot proved that the luminous and stratified appearances obtained in carbonic acid vacua do not arise from any peculiar action of the inductive coil, whatever the real cause of the phenomena may ultimately prove to be.

Geissler's Vacua Tubes.—It would be quite impossible, by any description, to do justice to the extreme beauty of the phenomena observed when the inductive discharge is passed through many of the tubes so ingeniously prepared by M. Geissler, of Bonn; neither indeed could any description, however correct, serve any useful purpose, as, in consequence of the almost impossibility of preparing two tubes precisely alike as to form, and as to the exact condition of the attenuated media they enclose, it is very difficult to find two which present the same

appearances; moreover, we are for the most part ignorant of the nature of the matter with which these tubes have been filled, so that Mr. Gassiot, in his investigations, was compelled to prepare his own tubes. "Though," he writes, "I had the opportunity of experimenting with upwards of sixty of Geissler's vacua tubes, in which many beautiful and novel results are produced, not being able to ascertain with accuracy what is the gas, which, however attenuated, must remain in each tube, and from most of them being constructed of a varied form in consequence of which the discharge presents, in the several portions of the same tube, an entirely different appearance, both of colour and in form of stratification, I was reluctantly compelled to lay them aside, and either to charge and exhaust each

FIG. 24.



tube myself, or have them charged and exhausted in my presence." By way of reference, we have, how-

ever, figured some of the most striking of these vacua tubes, and would beg to remark that Mr. Ladd, from whom they may all be procured, is constantly receiving novel accessions from Germany. In the Frontispiece the inductive discharge is represented as passing through a spiral tube, in which 25 bulbs have been blown. In the tube in the writer's possession, the light is white, with a pale green tinge, the effect of which is greatly exalted by placing behind it a black curtain ; after the discharge has ceased the tube remains for some seconds phosphorescent. A similar tube is shown in Fig. 24. The operator is warned in this and all the vacua experiments, not to employ more than two, or at most three, battery cells.

Fig. 25 is a similar spiral tube, containing only 16 bulbs.

FIG. 25.

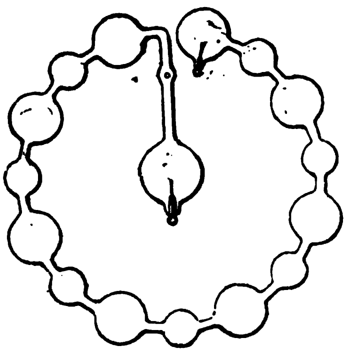


Fig. 26.—Bulbs pale green, the connecting tubes pale red, with stratifications ; phosphorescent after the discharge has ceased.

FIG. 26.

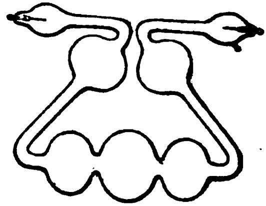
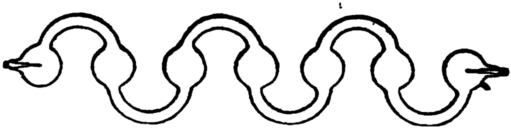


Fig. 27.—Bulbs pale green, connecting tubes red, with stratifications; phosphorescent.

FIG. 27.



Figs. 28 and 29 —These are beautiful experiments;

FIG. 28.

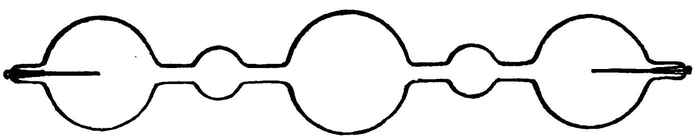


FIG. 29.

the bulbs in Fig. 28 vary from five inches to three in diameter; the centre bulb, and the two smaller ones,

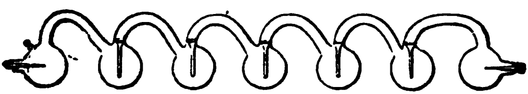
are filled with a pale green light, with magnificent stratifications, the connecting tubes pale red; the bulb in connection with the negative terminal is of a delicate mauve colour; that connected with the positive is red; but by turning the commutator, these colours change places; the stratifications are urged from the negative towards the positive terminal. In Fig. 30 the left-

FIG. 30.

hand bulb is of uranium glass, which gives the characteristic yellow colour; the tube connecting it with the centre bulb is of lead glass, and the colour of the light is blue, and the centre bulb is pale green.

Fig. 31.—The bulbs are filled with a pale green

FIG. 31.



light, except the terminal ones; the negative being mauve and the positive pale red; the connecting tubes are pale red and beautifully stratified; when the discharge is suspended the bulbs remain for some seconds phosphorescent.

Fig. 32.—The spirals are made of uranium glass,

FIG. 32.

which come out of a fine green colour; the centre bulb

is pale red; the positive bulb is red and the negative mauve; this is a nitrogen vacuum.

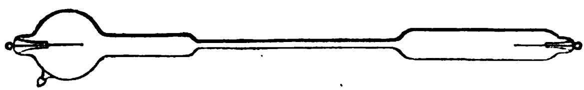
Fig. 33.—The spirals in this tube are enclosed in two separate tubes, one of which is filled with solution

FIG. 33.

of disulphate of quinine and the other with water, through which a few drops of horse-chesnut bark have been diffused; the light on the spiral tube is red, surrounded on the quinine side by a beautiful blue, and on the œsculine side by a fine green.

Fig. 34.—When the vacuum in this tube is pure

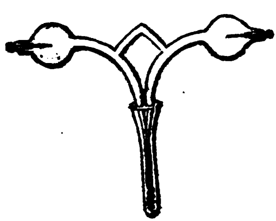
FIG. 34.



carbonic acid, the light is white; when pure hydrogen, the centre bulb is pale green, stratified, and the connecting tubes vivid red; when from bi-chloride of tin, the bulbs are pale blue, and the connecting tubes yellow.

Fig. 35.—This form of tube is intended for medi-

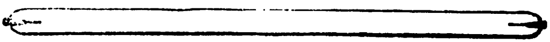
FIG. 35.



cal use; it furnishes the practitioner with an excellent and convenient means of examining the throat, for which purpose the tube enclosing the spiral is introduced at the mouth, and the inductive discharge passed through the bulbs, which have been filled with carbonic acid and well exhausted; a brilliant white light is produced, which illuminates the interior of the mouth and throat.

Tubes of the simple shape shown in Fig. 36, are

FIG. 36.



well adapted for observing the nature of the discharge, and the stratification in different gaseous vacua.

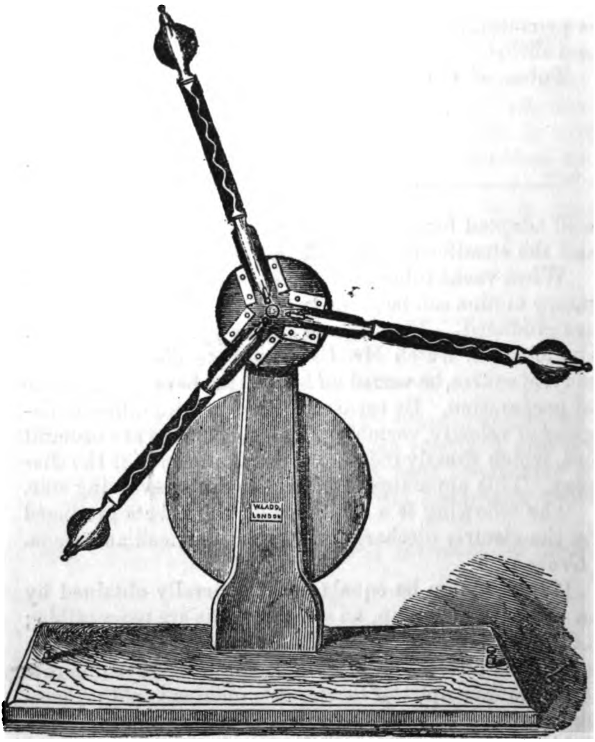
When vacua tubes are so arranged that continuous rotatory motion can be given to them, very beautiful effects are produced. Figs. 37 and 38 (see pp. 68 and 69) show the mode in which Mr. Ladd mounts his tubes; they may, of course, be varied *ad libitum* in shape and in mode of preparation. By turning the wheel with different degrees of velocity, various optical phenomena are brought out, which greatly increase the magnificence of the display. This apparatus is called Gassiot's revolving star.

The following is a summary of the effects produced by the electric discharge through Torricellian vacua. (*Grove.*)

If the vacuum be equal to that generally obtained by an ordinary air pump, no stratifications are perceptible; a diffused lambent light fills the tube. In a tube in which the rarefaction is carried a step further, narrow striæ are perceptible, like those obtained with phosphorus vapour. A step further in rarefaction increases the breadth of the bands. Next we get the conical or cup-shaped form; and then, the rarefaction being still higher, we get a series of luminous cylinders of an inch

or so in depth, with narrow divisions between them. Lastly, with the best vacua which have been obtained, there is neither discharge, light, nor conduction. The

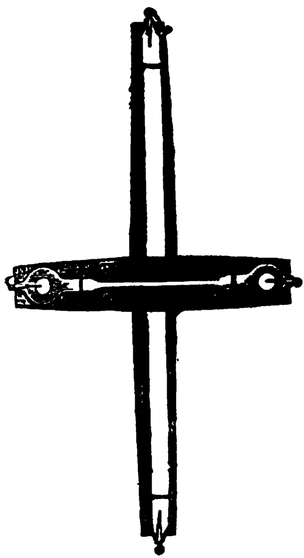
FIG. 37.



fact of non-conduction by a very good Torricellian vacuum was first noticed by Walsh, subsequently care-

fully experimented on by Morgan, and afterwards by Davy; the latter did not, however, obtain an entire non-conduction, but a considerable diminution both of light and conducting power. From these experiments it may be concluded that in vacuo, or in media rarefied beyond a certain point, electricity will not be conducted, or, more

FIG. 38.



correctly speaking, transmitted, an extremely important result in its bearing on the theory of electricity.

The following is Mr. Grove's view of the *rationale* of the phenomena of stratification. When the battery contact is broken, there is generated the well-known induced current in the secondary wire, in the same direction as

the original battery current, to which secondary current the brilliant effects of the coil are due; but in addition to this current in the secondary wire, there is also a secondary current in the primary wire, flowing in the same direction, the inductive spark at the moment following the disruption of contact, completing the circuit of the primary, and thus allowing the secondary current to pass. This secondary current in the primary wire produces, in its turn, another secondary, or what may be termed a tertiary current in the secondary wire, in an opposite direction to the secondary current. There are thus almost synchronously two currents in opposite directions in the secondary wire; these, by causing a conflict or irregular action on the rarefied medium would give rise to waves or pulsations, and might well account for the stratified appearance. Mr. Grove quotes the following experiment as strongly in favour of this theory. It is obvious that the secondary must be more powerful than the tertiary current. Now, supposing an obstacle or resistance placed in the secondary circuit which the secondary current can overcome, but the tertiary cannot, we ought, by theory, to get no striæ. If an interruption be made in the secondary current, in addition to that formed by the rarefied medium, and this interruption be made of the full extent which the spark will pass, there are, as a general rule, no striæ in the rarefied media, while the same vacuum tube shows the striæ well if there be no such break or interruption. The experiment was shown by Mr. Grove, in a lecture, at the Royal Institution (January 28, 1859), with a large vacuum cylinder (16 inches by 4) and Mr. Gassiot's micrometer-electrometer; this tube showed numerous broad and perfectly distinct bands when the points of the micrometer were in contact; but when they were separated, to the fullest extent that would allow sparks to pass, not the slightest symptoms of bands or striæ

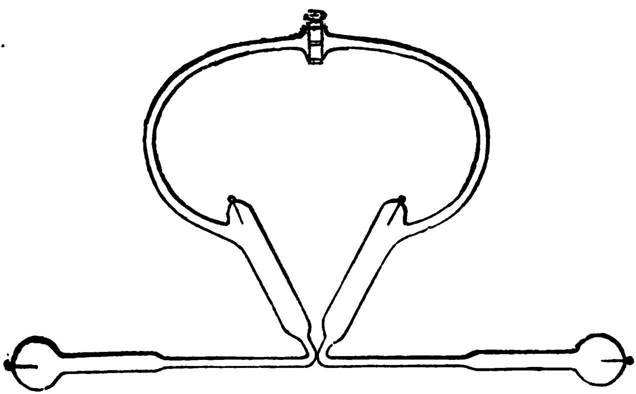
were perceptible, the whole cylinder being filled with an uniform lambent flame. With a spark from the prime conductor of the electrical machine, the striæ do not appear in tubes which show them well with the coil; occasionally, and in rare instances, striæ may be seen with sparks from the electrical machine, but not when the spark is unquestionably single. All this Mr. Grove thinks is in favour of his theory; but without regarding that as conclusive, or as a proved *rationale*, it is clearly demonstrated by the above experiments, that the identical vacuum tubes which show the striæ, with certain modes of producing the discharge, do not show them with other modes, and that therefore the striæ are not a necessary condition of the discharge itself in highly-attenuated media, but depend upon the mode of its production. Certain experiments, described by Mr. Gassiot (*Phil. Trans.*, 1859), do not harmonise with Mr. Grove's view. He found that when a Leyden discharge was sent through a vacuum tube, stratifications, as clear and as distinct as those from an Induction Coil, may be obtained by reducing the intensity of the discharge, by the introduction into the circuit of a piece of wet string; he hence inferred that in Mr. Grove's experiment, the absence of striæ, when the circuit was interrupted, was due to the heightened intensity of the discharge. He repeated Mr. Grove's experiment with the large cylinder, and obtained a similar result; the stratifications were entirely destroyed when the secondary circuit was interrupted, but they were restored when a second interruption was made in the circuit, and this closed by a wet string; in this case it is evident that the appearance of the striæ does not depend upon the conflict of secondary and tertiary currents, but upon the manner in which the discharge passes. Mr. Gassiot found, moreover, that when, by means of an interrupted discharge, the stratifications are destroyed, they are reproduced in a carbonic acid

vacuum tube when heat is applied to the caustic potash; here the increased resistance arises from the greater density of the matter formed in the tube; and the experiment favours the view of Mr. Gassiot, viz., that the stratifications arise from the effect due to pulsation or impulses of a force acting on highly attenuated matter.

Spectra in highly rarefied Gases of different kinds, during the passage of the Electrical Discharge.—In order to observe and analyze the spectra, Professor Plücker concentrated the luminous electrical discharge current in thermometer tubes whose internal diameters were nearly the same for the different gases examined,

FIG. 39.

c



being about 0·6 millimetre. Fig. 39 shows the form of the perfect separate gas tubes, as well as the manner in which they may be connected on a piece of board, so that the narrow parts of both (at the parts where they are bent at an angle of rather more than 90°) touch one

another, and have exactly the same direction. By turning the glass cock (*c*) the gases in the two tubes could be put into communication. The spectra were observed by means of a telescope (such as that employed by Fraunhofer, in the observation of the lines of the solar spectrum) without angular measurements. This was set up at a distance of from 4 to 5 metres from the vertical line of light in the tube. The flint-glass prism, whose refractive angle was 45 degrees, was fastened immediately before the object glass, whose aperture was 15 Paris lines.

1. *Hydrogen.*—Almost the whole of the light is concentrated into three bands,—namely, a dazzling red, at the extremity of the spectrum; a beautiful greenish blue; and finally a violet of inferior brightness, whose distance from the greenish blue is about two-thirds of the distance of the latter from the dazzling red. In the narrow tube the electric light stream appears red.

2. *Nitrogen.*—In the spectrum of this gas all the colours are fine, none of them being faded, as in the broad spaces lying between the bright bands of the hydrogen spectrum. In the spaces of the red, orange, and yellow, there are about fifteen narrow dark-grey lines at nearly equal distances apart; six of these belong to the orange and yellow; both of these colours are beautiful. The red, in the direction away from the orange, is shaded off into brown, but becomes brighter and purer towards the extremity of the spectrum, which stretches beyond the dazzling red bands of the hydrogen spectrum. A broad green space is separated from the yellow by a narrow black band. The greater part of this space appears shaded with black in the direction away from the black band. On a more careful examination, this shading is seen to consist of very fine black lines, which are at equal distances apart, but nearer together than the previously mentioned bands on the red, orange, and yellow. The rest of the green

space is again subdivided. The green is bordered by two beautiful bright blue bands, which are sharply separated from one another, and from the green, by narrow black bands. The blue and red violet ends of the spectrum form nine sharply-bordered violet bands, alternating with dark ones. The fourth and fifth bright bands, separated by a black band, possess the most light; the four following ones are less prominent; the last one, however, which forms a sharp boundary to the whole spectrum, is the most distinct. The light of the discharged current in the narrow tube is *yellowish-red.*

3. *Carbonic Acid.*—Six bright bands sharply separate the bright portion into five spaces, of which the two first are of equal breadth; the third, and especially the two last, are somewhat broader. The first of the six bands is situated on the extreme boundary of the red, the second is reddish-orange, the third greenish-yellow, the fourth green, the fifth blue, and the last violet. Both of the two first spaces are divided into three equally broad subdivisions by narrow black-gray bands, of which two always border upon the bright band. The first space is brown-red; the second dirty-orange and yellow; the third and fourth spaces are of rather faded green, and much subdivided by different degrees of shading; the fifth space, which is very faded, is divided into two equal spaces, which are shaded off from the red side towards the violet. After the last-mentioned violet band, another dark portion of the spectrum occurs, about as wide as the red-yellow portion. In this dark portion, three spaces are separated by three prominent and well-marked violet bands, whose breadth is of the same value as that of the before-mentioned six bands. The last of the three violet bands forms the visible boundary of the spectrum. The first of these three spaces, which is contiguous with the above six bright bands, is somewhat broader than

the third. Both are perfectly black. The second and middle space is about as broad as the first and third together, and is of a very dark violet colour. The first band, which at the moment of commencing was of an especially brilliant red, lost almost the whole of its brightness after the streams had passed through the tube for a long time. This was occasioned by the decomposition of the gas into carbonic oxide and oxygen, the latter combining with the platinum of the negative electrode, and forming oxide of platinum, which was deposited of a yellow colour upon the neighbouring internal glass surface.

4. *Ammonia.*—On exhausting a single tube that has been filled with ammonia, and passing the current, a spectrum was produced which was evidently the result of the superposition of the two spectra for hydrogen and nitrogen; the ammoniacal gas was immediately decomposed into its constituents, and it was not possible to obtain the spectrum of the chemically combined gases. When one of the double tubes, Fig. 39, was filled with carbonic acid, and the other with hydrogen, and then exhausted as far as possible, a greenish white light was obtained in one tube and a red light in the other. On now putting the two gases into communication, by opening the stop-cock, *c*, and observing the spectrum of the carbonic acid through the telescope by the prism, a dazzling red line was at first seen merely flickering now and then at the boundary of the spectrum, and soon took up and maintained a constant position; this was the red band of the hydrogen gas. The colour of the light in the two narrow tubes was the same—the two spectra had become constant and identical in kind.

5. *Oxygen.*—A good spectrum could not be obtained with this gas, on account of its gradual disappearance and combination with the platinum of the negative electrode. Oxide of platinum, of a yellow colour, was

deposited upon the neighbouring internal glass surface, showing, by reflected light, the colours of Newton's rings in a very beautiful manner. If the tube contains traces of hydrogen or nitrogen, metallic platinum is transferred to the glass surface. The colour of the electric light current in the narrow tube was at first red; it passed through a flesh colour to a green, and then through blue to a reddish-violet, and then became extinct, proving that no current can exist in absolute vacuæ.

6. *Binoxide of Nitrogen.*—This gas was decomposed, the spectrum for nitrogen being obtained with a modification evidently attributable to pure oxygen (a bright band near the red); this was gradually extinguished, and the result was the formation of the pure spectrum of nitrogen gas of a splendour which Pülcker had never before witnessed. Binoxide of nitrogen, present in so small a quantity as to be scarcely recognizable by the most sensitive balance, was thus chemically analyzed; with nitrous acid the red band due to the oxygen was at first of great brilliancy, but it gradually disappeared; the same was the case with protoxide of nitrogen.

7. *Aqueous Vapour.*—The electric current in the narrow tube showed the most beautiful deep red. The spectrum was that of pure hydrogen, with its three prominent bands, in comparison with the brightness of which the rest of the luminous divisions were so insignificant that here the shading off of colour and luminous intensity was scarcely to be recognised. The aqueous vapour had separated into its simple constituents.

8. *Iodine, Bromine, and Chlorine.*—Pure spectra have not yet been obtained with these substances, because the manner in which the tubes have hitherto been made did not admit of complete exclusion of the air. That which the three spectra have in common,

and by which they are distinguished, as far as present observations extend, from all other gas spectra, consists in lines of light, which at first are constant, but afterwards only flickering, and whose width is about the same as that of the narrow Fraunhofer's black lines. The chemical results hitherto obtained are summarised briefly by Plücker, as follows :—

1. Certain gases (oxygen, chlorine, bromine, and iodine vapour) combine more or less slowly with the platinum of the negative electrode, and the resulting compounds are deposited upon the neighbouring glass surface. When the gases are pure, we thereby gradually approach to a perfect vacuum.

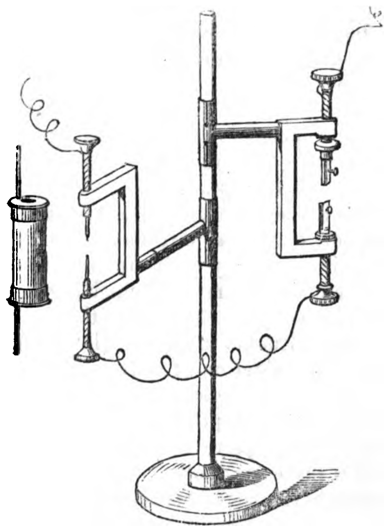
2. Gases, which are composed of two simple kinds, (aqueous vapour, ammonia, nitrous oxide, nitric oxide, nitrous acid) immediately split up into their simple constituents, and then remain unchanged, if these latter (ammonia) do not combine with the platinum. If one of the constituents is oxygen (in water, and the different stages of oxidation of nitrogen) this gradually disappears, and the other gas alone remains.

3. If the gases are composed of oxygen and a solid simple substance, complete decomposition by the current only takes place gradually, while the oxygen goes to the platinum of the negative electrode. (Sulphurous acid, carbonic oxide, carbonic acid). Carbonic acid is instantly decomposed into the gaseous lower state of oxidation, and into free oxygen, which gradually goes to the platinum. The carbonic oxide is gradually decomposed, by the oxygen leaving the carbon, and combining with the negative electrode.

Fig. 40 shows a very convenient arrangement for experimenting upon the spectra produced by different metals, comparing them with that produced by platinum. The metals, in the form of wires, are attached to screws, passing through clamps of vulcanite, which can be adjusted at any required height and angle by means

of the spring tubes connecting them with the upright pillar. The wires on the left-hand clamp are permanently platinum, those on the right-hand clamp may be

FIG. 40.



of any other metal or metals; they are held by pincers, so that they may readily be removed and replaced by others. The two lower screws are metallically connected. The two upper are connected with the secondary terminals of the coil, and then with the Leyden jar, as in Ex. 8, p. 37. A brilliant discharge takes place simultaneously between the wires in each clamp, provided the distances be properly adjusted, and the apparatus being accurately arranged before the spectrum box, one spark is reflected through a prism,

and the other is received directly through the slit; the two spectra immediately become apparent, one over the other, so that the peculiarities in each may be at once detected.

By employing the little capped glass tube, shown on the left-hand side of the figure, spectra may be obtained in various gases, the gas being passed through the tube while the discharge is taking place.

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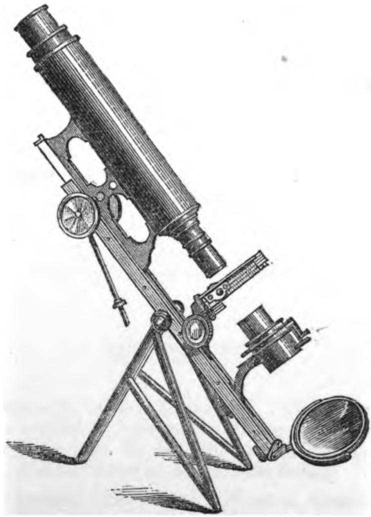

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The above, with magnetic stage and two eye-pieces ...	9	0	0
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Compressorium	0	15	0
Extra Eye-pieces ... ... 12s. and	0	15	0
Animalculæ Cage ... . 3s. to	0	6	0
Glass Micrometers, for measuring the diameter of various objects, 100ths and 1000ths	0	6	0
Micrometer mounted in brass frame, with screw adjustment fitted to eye-piece of Microscope	1	0	0
Slips of Glass, 3 inches by 1 ... per packet of 3 dozen	0	2	6
Glass Circles for Covers, per ounce...	0	6	0
Ditto Squares ,, ,, ...	0	4	0
Canada Balsam, pure Glycerine, Dean's Gelatine, Asphalt, Gold Size, &c. ... ... per bottle, 1s. to	0	1	6
Machine for cutting Sections of Wood ... 7s. 6d. to	1	1	0
Turntable for building up Cells and varnishing the edge of covers...	0	7	6
Brooke's Double-connector	1	0	0
Valentin's Knife, in case	0	16	0
Set of Microscopical Dissecting Instruments, in case ...	1	10	0
Maltwood's Finder	0	7	6
A large assortment of Microscopic Objects, sections of teeth, bone, &c.	0	1	6
Insects, Infusoria, and Vegetable structures ... 1s. to	0	1	6
Anatomical Injected Preparations ... ... from	0	2	6
Microscopic Photographs	0	2	0
Mahogany Cabinets, for holding 264 objects, and place for apparatus	1	7	6
Mahogany Cabinet, with 19 drawers, holding 360 objects, with glass door	3	3	0
Ditto, ditto, holding 500 objects, with place for apparatus...	4	4	0
Glass Trough, for fixing fish, &c.	0	5	0
Glass Dissecting Trough	0	4	0
Dr. Beale's Cabinet, for Chemical Analysis, containing the following :—Platinum foil, test tubes, pipette, urinometer, graduated glass measure, spirit lamp with wire ring, watch-glasses, glass slides, thin glass covers, and 8 reagents in glass bottles, with capillary orifices ...	1	5	0

W. Ladd supplies the following Works.	£	s.	d.
Quekett's Practical Treatise on the use of the Microscope ...	1	1	0
The Microscope, by Dr. Carpenter...	0	12	6
How to Work with the Microscope, by Dr. Lionel Beale ...	0	5	6
Half-hours with the Microscope, by Dr. Lankester ...	0	2	6
Hogg on the Microscope	0	6	0

ACHROMATIC OBJECT-GLASSES FOR MICROSCOPES.

Object-Glasses.	Angular Aperture.	Price.			Magnifying Power with the various Eye-Glasses.		
		£	s.	d.	A	B	C
2-inch	15 degrees	2	10	0	20	30	40
1½ ,,	20 ,,	2	15	0	40	55	70
1 ,,	15 ,,	1	11	6	60	80	100
1 & 2 ,,	25 ,,	3	3	0	,,	,,	,,
½ ,,	65 ,,	4	4	0	100	130	180
¼ ,,	95 ,,	4	4	0	220	350	500
⅙ ,,	135 ,,	6	0	0	320	510	700
⅛ ,,	150 ,,	7	7	0	400	670	900

TELESCOPES.

	£	s.	d.
Five-ft. 6 in. Astronomical Telescope, 4½-in. aperture, six Astronomical eye-pieces, the magnifying powers ranging from 50 to 400 diameters, reflecting prism for viewing the sun and moon, mounted on equatorial stand of improved construction	100	0	0
Four-ft. Astronomical Telescope, 3¼-inch object-glass, 5 eye-pieces, and brass tripod, with horizontal and vertical movements, packed in mahogany case	31	10	0
3-ft. 6-in. ditto, 3 eye-pieces, 2¾-in. object-glass, in mahogany case	21	0	0
3-ft. ditto, 3 eye-pieces, 2⅜-in. object-glass, in mahogany case.	15	0	0
2-ft. 6-in. ditto, 2 eye-pieces	10	0	0
Twenty-one-inch Navy Telescope	2	5	0
Eighteen-inch ditto	1	16	0
Fifteen-inch ditto	1	10	0
Day and Night Telescopes ... ... from	1	10	0

Pocket Telescopes of every description, and of best quality.

	£	s.	d.
Revolving Stereoscope, to hold two dozen glass slides ...	3	10	0
A large assortment of Glass Stereoscopic slides, from 4s. 6d. to	0	6	6

APPARATUS FOR ELECTRIC LIGHT POLARISATION SPECTRUM ANALYSIS.

	£	s.	d.
Duboscq's Electric Lamp	12	0	0
Lantern for ditto, with Condensers	12	0	0
Serrin's Electric Lamp	20	0	0
Mahogany Lantern for ditto	5	0	0
Miscroscope for either of the above, with best acromatic Objectives	10	0	0
Duboscq's Polarscope for above	12	10	0
Prisims of heavy Glass on Stand ... ... from £2 to	3	10	0
Ditto Quartz.			
Prisms of Six Glasses of various density	3	10	0
Bottle Prisms of Bisulphide of Carbon ... from 12s. to	0	18	0
Prism with moveable Slides, on Brass Stand, with adjusting screws	6	0	0
Four-inch Condenser, on Stand, for focusing image on screen			
Kinchhoff and Bunsen's Apparatus for Spectrum Analysis	6	0	0
Ditto, with Prism for observing two Spectra at one time ...	6	10	0
Ditto, ditto, as constructed by Steinheil	10	0	0
Bunsen's Burners for above ... from 4s. 6d. to	0	10	0
Biot's Reflecting Polariscope, with apparatus	5	5	0
Tourmaline Polariscope, to illustrate the system of coloured rings in crystals, &c.	2	2	0
Selenites, of various devices ... ... from	0	5	0
Specimens of unannealed glass of various shapes, from	0	3	0
Plates of Arragonite, Quartz, Topaz, Nitre, Calc-Spar, Borax, &c., for exhibiting the coloured rings, from	0	5	0
Apparatus to show the polarising structure communicated to glass by pressure ... ... from 7s. 6d to	1	1	0

Rhombs of Iceland Spar.
Polished Plates of Tourmaline.
Double and single Image Prisms.
Polarising bundles of Crown Glass.
Polariscopes fitted to Miscrosopes.
Selenite Discs.

PHANTASMAGORIA LANTERNS, &c.

	£	s.	d.
Phantasmagoria Lantern, 4½-inch condensers	4	10	0
Two of the above, with Dissolving Apparatus	10	0	0
One ditto, 3½-inch condenser	3	3	0
Two of the above, with Dissolving Apparatus	7	5	0
One ditto, 3-inch condenser	2	10	0
Set of Astronomical Slides, with Rackwork, 2½-inches ...	3	15	0
Set of ditto, 3-inch	5	0	0

		£	s.	d.
Set of Astronomical Slides, 14-inch		1	10	0
,, Natural History		1	10	0
,, Botanical		1	15	0
English and Foreign Views, &c., &c., each	from 5s. to	0	7	6
Chromatropes, each	from 7s. 6d. to	0	10	0

LADD'S IMPROVED INDUCTION COILS AND APPARATUS.

Induction Coil, to give $1\frac{1}{2}$-in. spark in air	10	10	0
Ditto ditto $2\frac{1}{2}$-in. ditto	12	12	0
Ditto ditto 4-in. ditto	15	15	0
Set of five Grove's Batteries, with platina plates $5 \times 2\frac{1}{4}$-in., in tray	3	0	0
Ditto ditto ditto $6\frac{1}{4} \times 3$-in.	5	5	0
Apparatus consisting of glass tube with two platinum terminals, with brass plate and glass receiver to fit upon air pump for experiments with Torricellian vacuum ...	1	10	0
Gassiot's Torricellian Vacuum tube (Fig. 15)* for broad, cloudy stratification (Fig. 16)	1	5	0
Ditto packed in case	1	12	0
Uranium glass tube mounted on stand, with stopcock £1 1s. to	2	2	0
Glass tubes for showing the Aurora Borealis, fitted with stopcock, and capable of being charged with various gases, from 2 to 6-ft. long, and 1 to 4-in. diameter (Fig. 13)			
Apparatus for showing the rotation of a spark round an Electro-magnet (Fig. 11)	3	10	0
Ditto ditto (Fig. 12)	1	10	0
Bar Electro-magnet for experimenting with the electric spark	1	0	0
Egg-shaped glass, with stopcock and sliding wire (Fig. 14) £1 15s. and	2	5	0
Gassiot's Cascade (Fig. 9) ... ... £3 and	3	10	0
Gassiot's Revolving Star (Figs. 37 and 38) ... £3 3s. to	4	10	0
Geissler's sealed vacuum tubes. These tubes have been charged with the various gases and then exhausted to the utmost and hermetically sealed.			
Carbonic acid vacuum tube with stick of caustic potash at one end (Fig. 19) ... ... £1 5s. and	1	10	0
Ditto with carbon terminals...	1	5	0
Double Garland tube (Fig. 24)	2	0	0
Single ditto ,, 25	1	10	0
Vacuum tube (Figs. 26, 27, 29, and 31) each	1	5	0
ditto ,, 28, 32, 33, ,, ...	1	10	0
ditto ,, 30 ,, ...	1	1	0
ditto ,, 34 ,, ...	0	12	6

* See "Treatise on the Induction Coil," by Dr. H. M. Noad, F.R.S., &c.

		£	s.	d.
Vacuum tube for surgical purposes (Fig. 35)		1	1	0
ditto „ 36 ...	15s. to	1	1	0
ditto of Uranium Glass	15s. to	1	10	0

A variety of other tubes always in stock.

		£	s.	d.
Uranium Glass vessel for showing fluorescence		0	5	0
Block of Uranium Glass, $6\frac{1}{2} \times 3\frac{1}{4} \times 1$ in mahogany case ...		1	15	0
Glass tubes containing Becquerel's Phosphorescent powders.				
Revolving colour disc for showing white light, also for proving that the Induction Spark is not continuous ...		0	7	6
Spotted Jars	7s. 6d. to	2	2	0

APPARATUS FOR FRICTIONAL ELECTRICITY.

				£	s.	d.
24-inch Plate Electrical Machine, mounted upon the best principle, with Electrometer attached				10	10	0
18-inch	ditto	ditto	ditto	7	0	0
15-inch	ditto	ditto	ditto	5	0	0
12-inch	ditto	ditto	without Electrometer	4	0	0
9-inch	ditto	ditto	ditto,	3	0	0

Cylinder Electrical Machines made to order.

		£	s.	d.
Improved form of Electrometer with Condenser (very delicate)		3	3	0
Quadrant Electrometer...		0	7	0
Cuthbertson's Self-acting Electrometer		1	18	0
Bennet's Gold Leaf Electromer	14s. to	1	10	0
Medical Jar		0	5	0
Henley's Universal Discharger, with Press and Table,	£1 5s. and	2	0	0
Electrical Cannon, with brass carriage		0	18	0
Electrical Flask, with cap and valve		0	6	0
Electrical Pistol		0	5	0
Luminous Conductor		0	18	0
Electrical Sportsman	15s. and	1	1	0
Egg-stand		0	7	6
Egg-shape Glass, with stopcock and sliding wire for shewing light in vacuo, used with Induction Coil		1	15	0
Hand Spiral	3s. 6d. and	0	5	0
Set of five spirals		1	8	0
Luminous Woods in frame		0	10	6
Revolving Spiral on stand		0	8	6
Image Plates, with brass stand	8s. 6d. and	0	10	6
Dancing Figures made of pith		0	1	0
Electrical See-saw		0	12	0
Pith ball Stand		0	5	6
Pith Balls	per dozen 9d. and	0	1	0
‾ rved Head with hair	3s. 6d. and	0	5	6

	£	s.	d.
Diamond Jar ... ... 7s. 6d. and	0	12	0
Bucket and Syphon	0	5	0
Electrical Orrery	0	7	6
Sturgeon's Apparatus for firing gunpowder, &c. ...	0	9	0
Insulated brass or wood stands			
Electrical Spider	0	1	0
Electrical Obelisk	0	7	0
Thunder House	0	7	0
Fire House...	0	12	6
Gamut of Bells	1	10	0
Set of three Bells	0	7	0
Insulated Stool	0	12	0
Jointed Discharger ... ... 7s. 6d., 9s., and	0	10	6
Discharging Rods	0	3	6
Apparatus for shewing the falling star	0	15	0
Electrical Cylinders			
Glass Handles and Legs			
Brass Chain ... ... per yard	0	0	4
Amalgam ... ... per box	0	1	0
Circular Glass Plates, for Electrical machines			
Conductors			
Leyden Jars ... ... from	0	3	6
Brass Balls ... ... from	0	0	9
Electrophorus ... ... 10s. and	0	15	0
Glass Jar with moveable tin coatings	0	10	6
Set of Electrical Apparatus for educational purposes, consisting of the following articles:—9-in. Plate Electrical Machine, Leyden Jar, Pith-ball Stand, Jointed Discharger, Hand Spiral, Brass Clamp, Head of Hair, Amalgam, and Chain, packed in coloured deal case with lock and key	5	5	0

VOLTAIC AND MAGNETIC APPARATUS.

Medical Galvanic Coil of improved construction, which can be regulated so as to apply it either to an infant or to the most obstinate cases, in mahogany box	4	4	0
Medical Galvanic Machine, in mahogany box	3	3	0
Ditto, ditto, small size	2	2	0
Improved Magneto-Electric Machine, for medical purposes, in mahogany case	2	5	0
Magneto-Electric Machines for firing Abel's Fuzes, from	3	10	0
Electro-Magnet ... ... 6s. and	0	10	6
Mahogany support for ditto	0	5	0
Galvanometer, on stand	0	10	0
Galvanometers with Astatic Needle, on stand, with levelling screws and glass shade ... ... from	1	8	0

	£	s.	d.
Barlow's Wheel	0	10	0
Sturgeon's Disc, to go with the above	0	3	6
Oersted's Experiment ... ...7s. 6d. and	0	10	0
Apparatus for showing the rotation of Electro-magnet between the poles of a soft horseshoe	0	10	0
Richie's Eletro-magnetic Apparatus, consisting of horseshoe-magnet, on stand, with levelling screws, Armature, Ampere's Bucket, wire frame, helical coil, and two flood cups	2	10	0
Marsh's Vibrating Suspended Wire...	0	7	0
Working Model of Telegraph, by which sentences may be transmitted	3	10	0
Apparatus for ringing a Bell by Electro-magnetism ...	1	1	0
Ditto, ditto, of improved construction ...	2	2	0
Meloni's Thermo-electric Battery of twenty-five pairs of Antimony and Bismuth Bars ... ... from	1	10	0
Smee's Batteries, pints	0	7	6
Ditto, quarts	0	10	0
Set of six Smee's Batteries in glass cells, in mahogany trough, with adjustments for raising it out of the cells; may be arranged for quantity or intensity... ...	3	10	0
Grove's Platinum Battery	0	12	0
Set of eight of Grove's Batteries, in glass cells and mahogany tray	5	5	0
Set of ten ditto in tray...	6	0	0
4 sets of ditto for Electric Light	24	0	0
Improved Coke Batteries, in glass or stoneware cells ...			
Brass Clamps for Batteries			
Glass and Porus Cells			
Platinum Foil and Wire ... ... per oz.	1	12	0
Platinized Silver ... ... ,,	0	10	0
Amalgamated Zinc Plates ... ... per lb.	0	1	0
Copper Wire, of all sizes, covered with silk or cotton ,,			
Set of Electro-magnetic Apparatus for educational purposes, consisting of an Electro-magnetic Coil-machine, Smee's Battery, Galvanometer, Richie's Experiment, Oersted's ditto, Electro-magnet and mahogany stand, Barlow's Spur-wheel and Permanent Magnet, packed in coloured deal case with lock	5	5	0

DRAWING INSTRUMENTS, &c.

	£	s.	d.
Sets of Drawing Instruments for youths 5s. 6d., 7s. 6d., and	0	10	6
Sets of Drawing Instruments in mahogany case ...	1	1	0
Ditto ditto ditto	2	2	0
Ditto ditto in German silver	2	10	0
Ditto very superior ditto	3	10	0

	£	s.	d.
Architect's case of ditto, ditto, for the pocket	2	2	0
Ditto ditto, best make, German silver ...	3	10	0
Drawing Pens ... ... 3s., 4s., and	0	6	0
Proportional Compasses, 6 inch ... ... £1 10s., to	2	10	0
Engineer's Pocket Compass	1	0	0
Ditto ditto best make, German silver ...	2	0	0
Bow Pen and Pencils			
Spring and Hair Dividers			
Spring Dividers, Pen and Pencil, the set ... 10s. 6d. to	1	5	6
Rolling Parallel Rules, 6 inch, 6s., 9 inch, 7s., 12 inch, 8s. 6d., 15 inch, 11s.			
Rolling Parallel Rules, brass, 1s. 6d. per inch			
Protractors			
Sectors			
Mahogany and Ebony T-squares			
Drawing Pins			

THEODOLITES.

LEVELS.

COMPASSES.

SEXTANTS AND QUADRANTS.

GLOBES.

Containing all the recent discoveries, from 6 to 25 inches diameter.

Orreries or Planetariums ... ... £1 10s. to	10	10	0
Gyrascopes... ... ... £1 5s. and	2	11	6

METEOROLOGICAL INSTRUMENTS.

Standard Barometers ... ... from	6	6	0
Pedestal Barometers, in mahogany, walnut, or rosewood frames ... ... £2 2s. to	7	7	0
Wheel Barometer ... ... £1 15s. to	6	6	0
Marine Barometer ... ... £3 3s. to	5	5	0
Marine Barometer and Simpiesometer in one instrument £5 5s. to	8	10	0
Portable metallic Barometer	4	0	0
Standard Thermometers ... ... 10s. 6d. to	1	1	0
Thermometers for registering extreme heat and cold from	0	8	6
Ivory Thermometers, in leather case ... 4s. 6d. to	0	10	0
Chemical thermometers, divided on glass			
Boxwood Thermometers ... ... from	0	1	0
Mason's Hygrometer	1	6	0
Rain-gauge in japanned tin or copper ... from	1	0	0

PNEUMATIC APPARATUS.

	£	s.	d.
Very superior large size double barrel Air Pump, with additional barrel for very accurate exhaustion, barometer gauge, &c., on strong mahogany stool	35	0	0
Ditto ditto smaller size, for table (Fig. 10)* ...	15	0	0
Grove's Pump, with 7-inch plate, mercurial gauge, and two clamps	5	0	0
Large size double-barrel Air-pump, with raised plate, 10 in. in diameter, gauge plate, mercurial gauge, clamp, and key	11	10	0
Second size double-barrel table Air-pump, with raised plate, 9 inches diameter, gauge-plate, gauge, and key ...	9	10	0
Ditto, ditto, with plate 8-inches in diameter, on stand (not raised), with gauge-plate, gauge, and key... ...	8	0	0
Ditto, ditto, without gauge-plate, gauge, and key ...	6	10	0
Third size double-barrel Air-pump, diameter of plate, 6½ in.	4	4	0
Smaller size double-barrel Air-pump, diameter of plate 5½ ...	3	10	0
Small size single-barrel Pump, 3½-inch plate	1	0	0
No. 2 ditto ditto, 4½-inch plate	1	7	0
No. 3 ditto ditto 5½-inch plate	1	10	0
No. 4 ditto ditto sloping barrel, 6½ inch plate	2	2	0
Flat Brass Plate, with sliding wire... 10s. 6d. and	0	13	0
Exhausting or Condensing Syringes	0	7	0
Ditto ditto in one instrument ...	0	10	0
Apparatus, consisting of Glass Cylinder and Piston, to show the effect of pressure upon gases	1	0	0
Fire Syringe	0	3	6
Bell Experiments ... ... 7s. 6d. and	1	0	0
Bacchus Experiment	1	8	0
Lungs Glass	0	6	0
Large size Hemispheres	1	8	0
Middle size ditto	0	16	0
Small size ditto	0	12	0
Filtering Cup, with Brass Plate	0	6	6
Three-fall Guinea-and-Feather Apparatus	1	1	0
Two-fall ditto	0	15	0
Tall glass Receiver for ditto ... ... 7s. 6d. and	0	10	6
Windmill (improved)	1	15	0
Double Transferer	1	16	0
Single ditto ... ... 12s. and	0	18	0
Bladder Frame and Lead Weights	0	8	0
Copper Bottle, Beam, and Stand	2	5	0
Fruit and Taper Stand	0	3	6
Syringe and Lead Weights	0	8	0
Balance Beam and Cork Ball, with counterpoise weight ...	0	10	0
Torricellian Experiment	0	15	0

* See "Treatise on the Induction Coil," by Dr. H. M. Noad, F.R.S., &c.

		£	s.	d.
Ditto, having the Barometer fixed in the cap of glass receiver		1	7	6
Glass Globe, with brass cap and stopcock for weighing air ...		0	8	0
Leslie's apparatus for freezing water		0	10	0
Breaking squares		0	1	3
Wire-cage for ditto		0	4	6
Brass Stopcocks	2s. 6d. and	0	3	6
Apparatus for showing fountain in vacuo		0	12	0
Tall Receiver for ditto		0	7	6

Ladd's Educational Set of Pneumatic Apparatus,

As supplied by him to the various Educational Societies, consisting of the following Articles:—

	£	s.	d.
Single-barrel Air-pump and Receiver, Brass Clamp, Filtering Cup for Mercury, Magdeburgh Hemispheres with handles, Bladder Frame and Weights, Guinea-and-Feather Apparatus, Fruit, and Taper Stand, Hand and Bladder Glass, Single transferer and Fountain Apparatus, Brass Pipe for ditto, Bell Experiment, Brass Syringe for instantaneous Light, Glass for Fountain and Guinea-and-Fountain Apparatus, and Plate for Top of Fountain Glass, packed in coloured case, with lock and key	6	6	0

HYDROSTATIC AND HYDRAULIC APPARATUS.

		£	s.	d.
Working Model of Bramah's Hydrostatic Presss,	£5, £15, and	19	0	0
Apparatus to illustrate the principle that fluids will rise to the same height, whatever the form through which they flow, ...		2	10	0
Tantalus Cup		0	10	0
Glass Syphon	2s. and	0	3	6
Glass Balloons, Divers, &c.	each	0	2	0
Ditto, ditto, with Tall Jar		0	12	0
Model of Centrifugal Pump		3	3	0
Model of Lifting Pump, with glass barrel		0	18	0
Ditto, of Forcing Pump		1	8	0
Model of Archimedes' Screw, with glass worm... ...		2	2	0
Ditto of Undershot Wheel		1	15	0
Ditto of Overshot Wheel		1	15	0
Ditto of Diving Bell, with Force-pump		1	1	0
Fountain Apparatus, consisting of strong metal vessels, stop-cock, condensing syringe, and set of jets		2	2	0
Tantalus Cup		0	10	0
Philosophical Water Hammer		0	5	0
Woolaston's Cryophorus	4s. and	0	6	0
Marcet's Steam Apparatus		5	0	0

ABEL'S FUZES FOR FIRING MINES AND CANNON BY MAGNETO-ELECTRICITY.

W. L. is appointed Sole Manufacturer of the above, by order of the Secretary of State for War.

OPERA AND RACE-GLASSES,

With achromatic eye-pieces, with ivory, pearl, tortoiseshell, enamelled, or leather mounts.

MAGNIFYING GLASSES,

For viewing prints and paintings.

SPECTACLES AND EYE-GLASSES

In every variety of mountings.

PHOTOGRAPHIC CAMERAS & APPARATUS OF ALL SIZES.

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AND OF

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Orders from Foreign Parts must be accompanied by a Remittance or Order for Payment in London. The greatest care will be taken to insure their safe arrival.

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Packing-cases charged Cost Price, and NOT *allowed for if returned.*

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